SOLUTION FOR INSTABILITY IN MAGNETIZING OF TOROIDIAL COIL WINDING

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ABSTRACT

This thesis described the solution for problem of instability of magnetizing process occurred to the current process. It was done at Universiti Malaysia Pahang from Faculty of Manufacturing and Vacuumschmelze (M) Sdn. Bhd. Pekan. The objective of the study is to define an improvement or solution to the problem of the current process that affect the products unit. The survey, observation, experiment and data recording were done at the company by visiting their production line. The data were then recorded and further analyzed for the determination of the real situation and what actually happen to the current process which lead to the uninform of the boundaries, angles and inductance of the toroidal coil. After the problem was determined, the solution then created. A machine, called as low cost semi-automated winding machine was design. Before the system finished some modification and suggestion were brought to the board to ease the operators do the process, including solution to the problem that they faced every day. The system created as the initial problem solution while the machine was finished to be fabricated. The machine design then created using software for all of its component including mechanical, electrical and electronics and programming. The machine then tested and the result compared to the result of the current process. For the comparison, the machine improved a lot of the units' criteria, and only few of the unit were rejected. The inductance or the main problem faced by the current process also very much improved as the graph of the tested unit show it can functioning at the required ranges of induction value. However, there are some weakness of the machine that needed to be accounted as improvement in the future

ABSTRAK

Tesis ini menerangkan tentang penyelesaian untuk masalah ketidakstabilan proses pemagnetisan yang berlaku kepada proses semasa. Ia dilakukan di Universiti Malaysia Pahang iaitu di Fakulti Pembuatan dan di Syarikat berasal dari negara Jerman, Vacuumschmelze (M) Sdn. Bhd. Yang terletak di Pekan. Objektif kajian ini adalah untuk menentukan penambahbaikan atau penyelesaian kepada masalah proses semasa yang memberi kesan kepada unit produk. Kaji selidik, pemerhatian, eksperimen dan proses merekod data telah beberapa kali dilakukan di syarikat itu dengan melawat operasi pengeluaran mereka. Data kemudiannya direkodkan dan dianalisis bagi menentukan keadaan sebenar dan apa yang sebenarnya berlaku kepada proses semasa yang membawa pengaruh dan kesan kepada keseragaman sempadan, sudut setiap pusingan wayar dan kearuhan gegelung toroidal. Selepas masalah itu telah ditentukan, penyelesaian kemudian diwujudkan. Sebuah mesin yang dipanggil mesin penggulungan kos rendah separa automatik direka bentuk. Sebelum sistem baru selesai disiapkan, beberapa pengubahsuaian dan cadangan telah dibawa kepada meja perbincangan untuk meringankan operator pengeluaran melakukan proses, termasuk penyelesaian kepada masalah yang mereka hadapi setiap hari. Sistem dicipta sebagai penyelesaian masalah awal sementara system mesin yang baru selesai direkabentuk. Reka bentuk mesin kemudian dicipta menggunakan perisian computer untuk semua komponen termasuk komponen mekanikal, elektrik dan elektronik dan pengaturcaraan. Mesin ini kemudian diuji dan hasilnya kemudiannya dibandingkan dengan proses semasa. Sebagai perbandingan, system mesin baru yang direkabentuk menambah perubahan banyak pada kriteria unit, dan hanya beberapa unit produk sahaja yang tidak melepasi pemeriksaan kawalan kualiti. Kearuhan atau masalah utama yang dihadapi oleh proses semasa juga bertambah baik sebagaimana yang ditunjukkan graf unit yang diuji, menunjukkan ia boleh berfungsi pada julat nilai induksi yang diperlukan. Walau bagaimanapun, terdapat beberapa kelemahan mesin yang perlu diambil kira sebagai penambahbaikan pada masa hadapan.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The thesis is about to solve the problem of instability magnetizing process of semi-circle winding that occurred caused by the manual process that currently used. This winding process was a main process to produce unit which was called as unit or well known as I.E.E. It was a product sensor founded and produced by a German-based company, VACUUMSCHMELZE GmbH & Co. KG. It was the most high-end unit which produced by this company. The process to produce this unit were completely done in VACUUMSCHMELZE Pekan Plant except for its core, which was produced in Germany. For more specific, the process involved to finish the unit are process of core baking, core casing and winding process.

This unit was used in many luxurious cars as sensor. It will be placed under passengers' seats. For this unit, it will be connected to complex electronics circuit board and functioning to detect the presence of human. The technology that used on this unit (which told to be confidential) able to sense the object that place on it was human or a dead body. The unit will sense the heat of human body and activate the functionality of every Supplemental Restraint System (SRS) - Airbag System located strategically at the every seats.

The company have always showed a great interest in order to improve the production of this unit I.E.E. as it was the most valuable and highly requested by customers that comes

from automobile manufacturers such as BMW, Mercedes Benz and Volkswagen. For most another units, the production were upgraded continuously and vigorously in order to smooth the production. Some the units produced by using high technology automated-machine that designed, constructed and built by Engineers and Technician in Pekan Plant.

Currently the production still done manually by hands which is the human energy still applied to bend wires and to wind the cores. The operators will be provided a set of gloves, crochet, goggle, table and chairs, specialized clamp unit, cut and U-shaped wires and unit cores. The operators were well trained before they transferred to production lines and to do run this process, the operators must have good skills and must be precise.

1.2 PROBLEM STATEMENT

The current method used cause instability magnetizing process despites of low number of units' production per hour. This is the main problem, which cause defects on products and make the unit not functioning well. Other than that, the current method also cause pain to the operators as the wire that need to be winded around the core was thick (1.60mm diameter) that cause huge amount of forces has to be applied to pull the wire and became worst as it was a repeating action. By hands production cause the units produced variance in dimensions of the finished units and the distances between the turned wires, which is not too good in consistency. This shortcoming will affect the performances and functionality of the unit. The both problem of magnetizing matter and number productivity confidently can be improved when a better method founded and introduced.

1.3 OBJECTIVES

The main objective of this thesis is to solve problem of instability magnetizing process of semi-circle coil winding that occur caused by the current process.

The specific objective regarding this topics were:

a. To identify problem that affect the induction in the toroidal coil winding.

b. To design the most optimal and applicable solution to minimize the defects.

c. To do validate between manual-winding process and new system of semi-automation machine.

The current method used to wind the coil has many weakness. The main weakness that faced was the instability magnetizing process. The data collected show that there are a huge of variation in induction value in a specific number of the units. This cause the unit production that passed lower compared to number of units produced. This is not a good as the defected units need to be reworked, and reproduced. It resulting the low production and not give the best performance during the machine or devices that used this unit functioning well.

The first phase is to collect data in order to define the problem that occurs during current winding process. The data collection including the production line observation and analyzing. The specific number of unit then tested to see its magnetizing process or induction value. It will be recorded and conclusion from the data analysis will be problem that identified.

The best way to solve the problem including in terms of minimize the defects was the second phase of the project. Designing process will be focus on the ways that able to produce significant units of low in induction current values variation.

The third phase will be the presentation and confirmation from VACUUMSCHMELZE that the machine able to minimize their problem. The presentation will be involve the manager, engineers in Process Technology Department.

There also some minor objectives given by company. During observations, some of the techniques used by operators to produce the units make them feel pains and may cause injuries. The studies of the good or better techniques were also done and will be explained briefly in the next chapters. The studies shows that many lack during both of the winding processes including from operators, products and its surrounding itself.

Some of the problem in production line were seen including in form of human error, occurring of non-ergonomic tool and posture and defect in unit (6102-X001) or products itself. In this proposal, the issues will be discussed briefly as detailed project studies. As explained before, there were some lack of the tools used in production line. These tools will improved and it will be discussed in the next chapters.

Machines will eventually replace humans in few roles. Machines can do many things more efficiently (and more cheaply) than humans. They'll mostly be able to create things that are created in bulks, such as packed food, or cars, electronics and other stuff like that. Machines will not be able to replace humans in everything though.

1.4 SCOPES OF RESEARCH

The scope is to make improvement and designing new method of winding process, summarize the information gathered from observation, survey, and propose new design considerations and layout a tentative schedule in order to minimize the instability of the magnetizing process or induction process in units. The findings of the research and analysis have led to ideas of possible energy savings and reduces manpower which will be further investigated.

First of all, this thesis is on purpose to present the idea about designation of mechanism and improvement through winding process. Based on the observation and survey, there have some consideration to improve the existing tools in winding process. The ideas of improvement are either semi-automation or fully automation.

The first part of the design proposal will focus on mechanism how to pull the wire through the hole of core. The design is to include material and design. The design also will be use pneumatic concept due to the tied space through hole of core.

The second part of the proposal is to bend the wire for make a number of turn to the core. This will include either using rotating or pneumatic to ensure the wire tightly with the core. This will also to ensure, there have no boundaries between wire and core.

The third part of proposal is to solve over the angle between numbers of turn. This part of proposal confidently will include only servo or stepper motor to rotate the core to the require angle. The implication of the designed will avoid the number of turn to closely or overlapped between each other of wire. The scope of the project were to replace human labor to semi-automated machine. This machine eventually will replace human in few roles. As known, machine can do many things more efficiently and even cheaper that labor cost. They able to do things in bulk. The new design machine will be developed to do winding process. Programmable Logic Controller (PLC) will be used to run the operations. Sensors which was

used to align the position of the core and the clamp will be decided, rather than the aligning the angle of rotation and moving parts. The machine will produces a high precision unit, due to the high finished machine. The machine also produces more units per hour, as the machine produces faster. To date, the machine to do this unit still not available in VACUUMSCHMELZE Pekan. This unit was introduced early in year 2014, and the production still done manually. The fully automated machine confidently were in the making, as informed, the unit were highly requested by automotive industries. The unit assumed to be sold for more years as the new technology still not developed and still not requested from the buyers.

1.5 SUMMARY

This automation design will give a positive impact to Vacuumschmelze because they will have a new system of winding process that has been improved and semi-automation machine that can do winding process. A robot or machine can make the process of winding smoothly run by almost 100% efficiency, if the machine made precisely built. The programming language that will run either PLC microcontroller or C++ language using Arduino. In advantages, this company is using PLC as machines controller and have engineer that can run the microcontroller.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter summarize about the current method applied, examples of types of winding machine available in markets, previous and latest studies, the researches and Sciences behind to fabricate coil winding machine. Before the studies began, observations, surveys have been done to gain the information regarding to the process of winding the specified unit. The main objective of this part is to summarize the information gathered from observation, survey, propose new design considerations and layout a tentative schedule. The problem statement has been analyzed throughout till the end of November. The findings of the research and analysis have led to ideas of possible energy savings and reduces manpower which have be investigated. The analysis then used to obtain the basic function of the systems and also been used to provide the new solution in order to create a better winding process and new machine layout.

The outcomes that can be gained throughout this chapter are:

- ✓ Determination of the new improved process of wound core units.
- ✓ Identification of the importance of the wire tension in wound core.
- ✓ To find the suitable control program of the machine.

2.2 PRODUCT QUALITY AFFECTED BY HUMAN FACTOR

Product quality was really related to the things that produced it. If a product was produced by man, simply it can be said that the man itself affected what the outcome that will be developed by man. According to (Subramaniam et al, 2008) it was usually believed that the most problems that faced in production line caused primarily by human factors. They also quoted that it is not 100% caused by the operators or the workers in production department. Instruction may be inadequate, the material used may defective or machine may cannot produce the good quality products. The journal said that the failures lead about 85% from the management control and only 15% come from the workers. For man power utilization, there are three commonly department that introduced. Total Quality Management (TQM), Production Planning and Control (PPC) and Maintenance. TQM involve of the quality matters of the products, PPC responsible to plan the process and supplies base on orders while he maintenance were responsible to all technical matter. The performance of human varies from time to time depending on the capabilities and time of their working hours. In other words, the production will be drop as the performance of the labor dropped. Improper ways to monitor the work of labors will lead low standard of production output and low quality of product. From the journals, the main factor that cause this problem was the attitude of the worker themselves. The analysis also shows that the worker tend to work in an average manner and for most of time the will be less or not good in productivity and this will lead toward the wastage of the planned production time. The industry usually will use system of working hours which call Production Breakdown. Some of the industry will operate for 12 hours in 2 shift or 8 hours in three shifts per day. The shift length can be divided into two, which are the Planned Downtime and Planned Operation Time. Planned downtime is really useful for a system that needed the operation to be stopped for some of the committees to do maintenance and do some improvement. Planned operation time is the proposed duration for production process by management.

2.3 MATERIAL OF THE UNIT

From the project briefing, the review on the winding process that need to be improvised was explained by VACUUMSCHMELZE Process Technology Department Manager (Sheikh Ali, 2015). He introduced the winding process as a process involved to produce unit, which is process where the wire was winded around core. To do this process, material – finish core and wire and tools – crochet needle, clamp, glove and goggle were needed. The copper wire with codename (2LW200 1.600 BROWN) come in rolls from supplier (supplier not mention, which told to be confidential). This wire then will be cut by operators in specific length which is in ranges of 660mm to 665mm long. Before it bended, the both end of the wire will tinned – the process of wire tinning will be undergoes to remove the insulator from the wire. It will be then bended to form 'U' shape with specific dimension as shown below by using special tool produced by engineers in department.

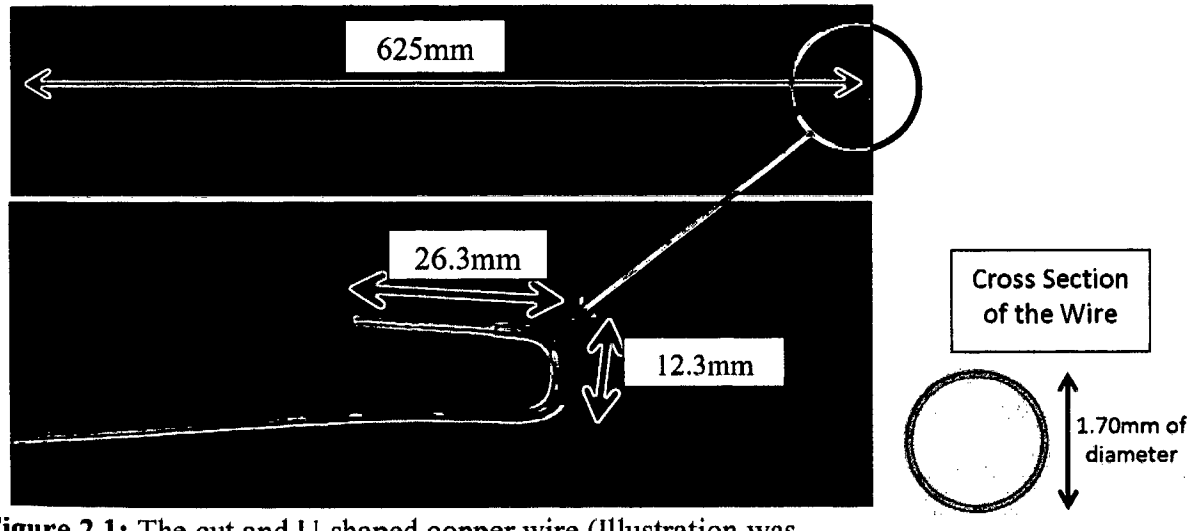


Figure 2.1: The cut and U-shaped copper wire (Illustration was obfuscated due to confidential issue and company copyrights.

Another main component needed to run the winding process of this unit was the cased cores or its code name (Core RC Vitroperm 500F). The metallic cores then was cased into plastic bobbin. The bobbin made from plastics-which is molded and have weight of 0.15g. The cores while were produced in Core Department located in VACUUMSCHMELZE

Hanau, Germany. The materials used to produce cores were 6 types of metals and compounded shaped into sheets (*details were not given, which told to be confidential*). The

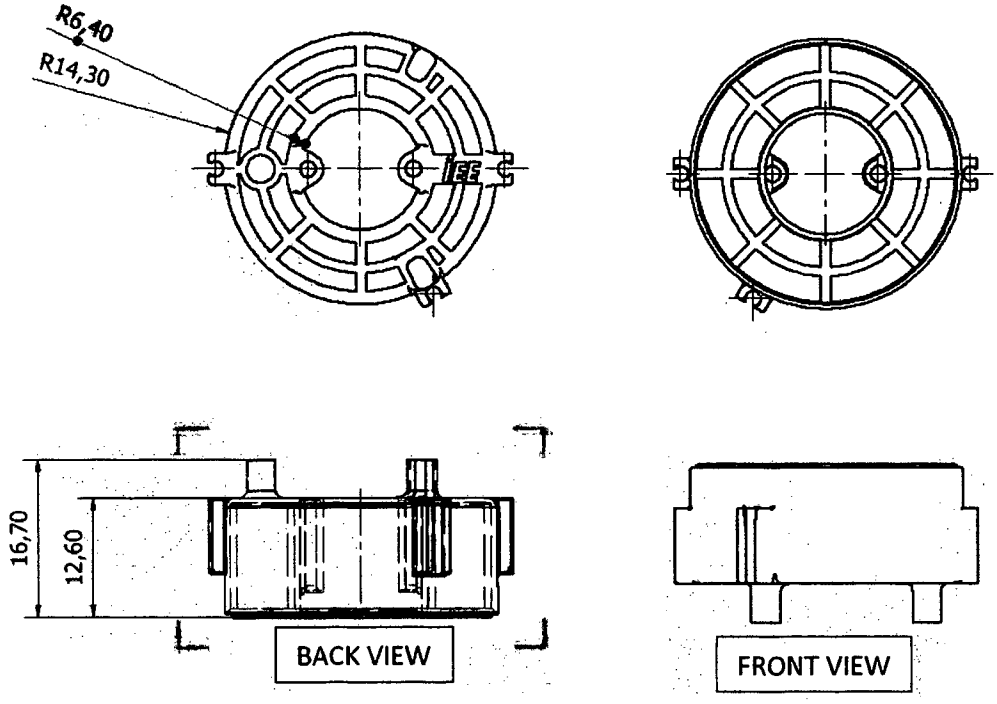


Figure 2.2: The dimension of the specified core

cores laters then will be brought to Pekan Plant in rolls and being baked at this plant. The cased core or bobbin specification was specified in figures below. The dimension of the toroidal core can be seen at the figure below. However, the actual figures of this type of core was restrictly not given to be published as it was a company confidential issue.

2.4 MAGNETIC FIELD OF TOROID

Before the unit furthered discovered, the fundamental of the inductance or magnetizing process should be really understood. By citation from (R Nave, non-dated) an

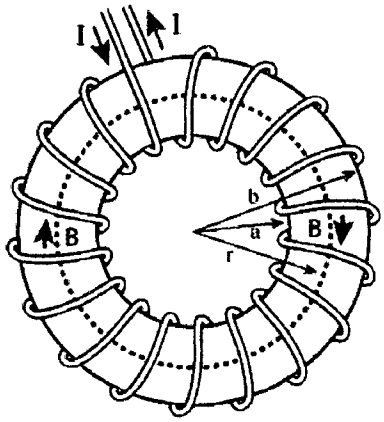


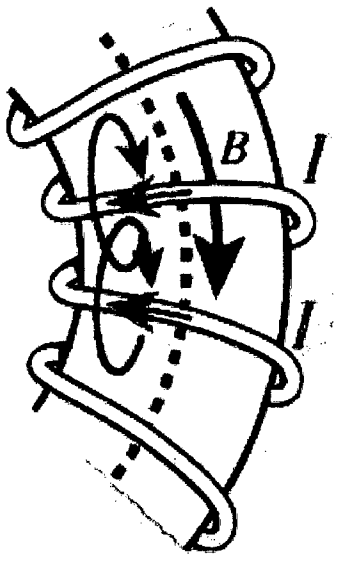
Figure 2.3: The current produced by induction

example of

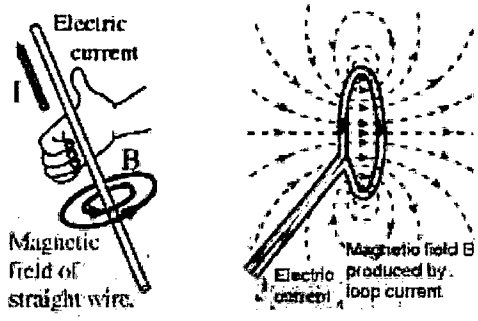
the power of Ampere's Law was can be defined by finding the magnetic field inside a toroid. The current presented by the dashed line is the number of loops times the current in each loop. Magnetic field, B can be given as:

$$B2\pi r = \mu NI$$

$$B = \frac{\mu NI}{2\pi r}$$



All of the loops of wire which make up a toroid contribute magnetic field in the same direction inside the toroid. The sense of the magnetic field is that given by the right hand rule, and a more detailed visualization of the field of each loop can be obtained by examining the field of a single current loop.



2.5 COPPER WIRE AS COIL

To imply the copper wire in the thesis, the characteristic of the material should be recognized. That was important in order to avoid defect to the product units as the improvement that will be done may cause the copper wire differs before it enter the improved system. The wire used for the winding process was types copper that is a very good electrical conductor. This is the main reason why copper was used in winding cores and coil instead of its property which is also as a metal that have a very good thermal conductivity. Heat cause the loss of many devices efficiency. For this unit, the both properties were really important in order to devices that use this unit functioning without any damages. One of the good characteristic of the copper was it wouldn't make very good water and gas pipes if it were highly reactive. Copper is a naturally hygienic metal that slows down the growth of microorganisms. Copper is a ductile metal and means that it can easily be shaped and drawn into wires. Copper pipes are lightweight because they can have thin walls. They don't corrode and they can be bent to fit around corners. This is the good fit for unit as the wire should be winded through all of the core. Copper and copper alloys are tough material. That makes them really suits to be used as tools and weapon. The property of toughness is important for copper and copper alloys in the modern era. They do not shatter when they are dropped or

become brittle when cooled below 0°C. Copper is nonmagnetic and non-sparking. Because of this, it is used in special tools and military applications. The alloys are harder, stronger and tougher than pure copper. They can be made even harder by hammering them - a process called work hardening.

2.6 MAGNETIC CORE

In inductors design, there are many basic core shape. The shape chose by developers and researchers depend on its purpose and application. The core usually made from metal. In this project, the core was produced in Germany. The composition of metal that used to produce this toroidal core was strictly cannot be exposed due to the confidential issue. The metal sheet that will be rolled to shape toroidal core then will be brought to the Core Department. Then it will be baked at 3000 degree Celsius in magnetic pressure.

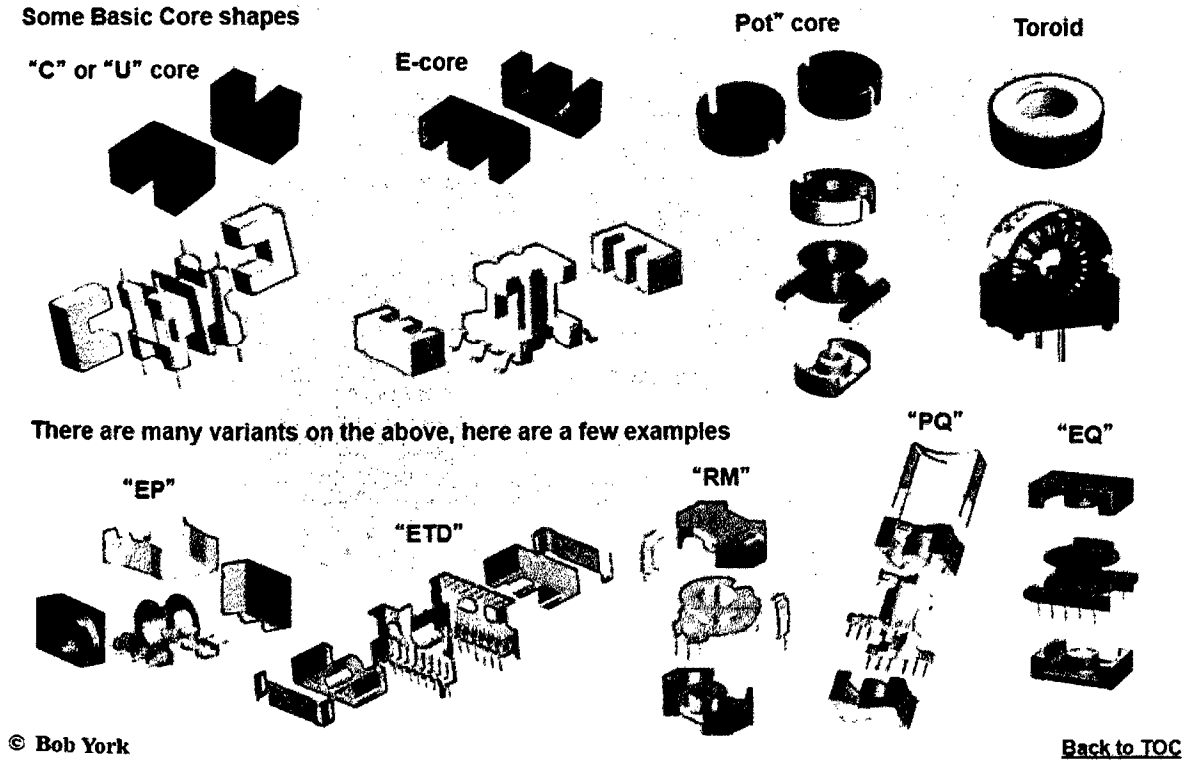


Figure 2.4: Types of core used in industries

2.7 SCIENCE OF ROUND AND RECTANGULAR CORE

The advance technology today has emerged the developers to invent many technologies and invention. They competing each other's to create better solution for many problems including in the development of the toroidal cores. They continuously create and invent various types and shapes of core that being used today. The shape of the core plays a big roles for the functionality of the sensors and transformers. The shape of the core significantly contribute a huge effect on the wire tension. Many of the core were fabricated in rectangular and round in shape. However, the toroidal core produced also in unique or irregular shape in some application, which is depend on its application and functions. From the studies, the most applications use huge numbers of round bobbin compared to the rectangular shape of core. The round shape of core provide uniform wound wire in terms of spaces or gaps between the turns of wire, while the rectangular shape core form uneven turns of wound wire and tend to break especially at the four edges. In other words, the tension or the wire was hard to be maintained. In designing machine, the shape of core really importance. The force applied on round core should be constant. It will be more complicated to rectangular shape core, which mean the force applied to pull the wire should manipulated according to the four edges. It causes the time needed to wind rectangular core longer compared to round core.

As the core clamped and rotated on the clamping device, the speed of the wire feeding onto the coil periodically changes - accelerates and decelerates as the radius of rotation varies (Shafie, 2013). As figured as follow, the radius of winding keep varies as the rectangular core rotates. This is the major factor that counted by the developers to choose round shape core in their products, as well the round core also give the best functionality of the devices created.

There were no major problems that faces to do wind the round bobbin, especially the unit specified in this thesis need to be wound half of round bobbin at once as the round core bobbin need to be wound at two separates section, N1 and N2.

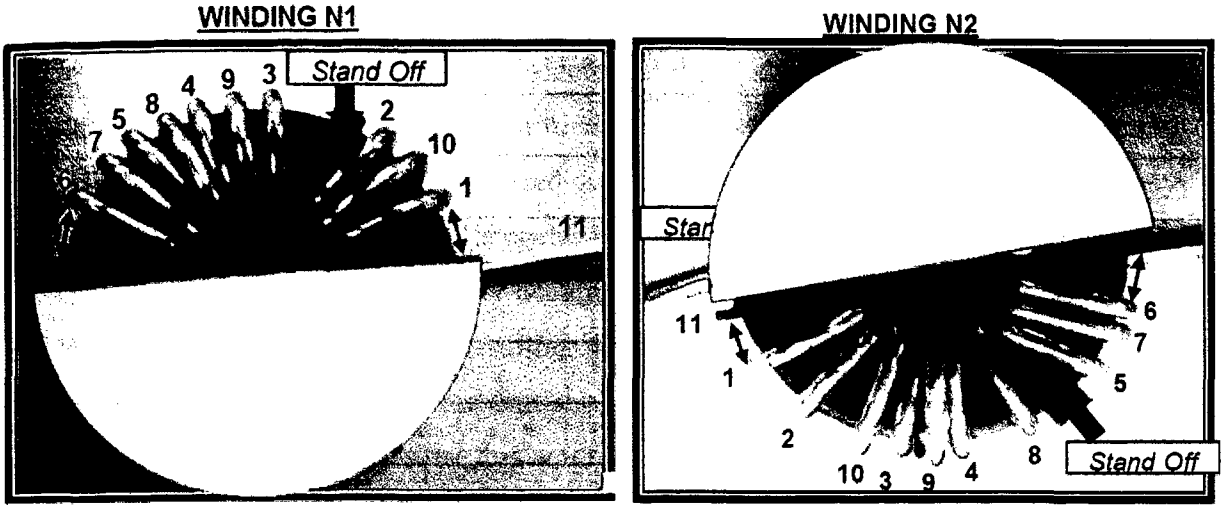


Figure 2.5: Two types of winding applied to the specified product unit

2.8 IMPORTANCE OF TENSION IN COIL WINDING MACHINE

The winding process began with the core will be placed and clamped at the specialized winding clamp. It will be clamped at the right position, which is upright between the section of N1 and N2. To do wind, forces or tension is required to pull the wire against the submission of loads, forces and resistance that occur on the wire as it being pulled, inclusive the force caused by the clamping and tensioner devices or crochet. Consistency of the forces or tension that applied to pull the wire was very important and bold in order to have a good wound unit, to avoid defect on the wire, to avoid wire scratch and non-wanted wire elongation. Constant forces to pull the wire is also important to achieving the aim of coil electrical characteristics to form stable performance of devices and electric conduction from wire turn to turn. The term 'pretension' is the term used when the force to the wire before and after the force applied. Pretension may cause by external forces inclusive the force of friction between wire and crochet and the moving of wire on the pulleys.

The winding process involves tension and forces in both static and dynamics. The tension dynamically started when the wire meets the bobbin. The tension of wire, the tightness and looseness of the wire wound on the core, was depend on how the mechanism of wire pulling successfully controlled.

Constant amount of force or tension that applied during pulling wire process was very important. The factors included to be considered on the quality of the wound core including bobbin size, bobbin shape, number of turn, winding speeds, acceleration and deceleration rates. The challenges that may be happened during the machine running were the wire may damage, lax and wander and causing irregular wire turns when required amount tension error occurred. One of the problem that may occurred, when the force applied too much and too big, the wire will elongated, which resulting the diameter of the wire became thinner. This should be really concentrated as the unit should be wound at the specific criteria, which important in order to the devices use this unit not fail.

The unnecessary amount of force or tension applied can cause the changes in the wire characteristics and damage the core's surface during winding process. If the wire randomly wound at the same number of turns, the total length of each wire per unit will be varies. The winding will be better if the wire really stretched during winding process, thus the length of wire needed to wind the core become less. The result by reducing the total length of the wire is the resistance will be reduce. The longer the coil wire has, the higher the resistance of the coil.

To control the tension during the winding process, the speed of the motor that used to pull the wire should be good controlled. In order to achieve the required speed of the motor, proportional-integral-derivative controller (PID controller) which is a control loop feedback mechanism (controller) commonly used in industrial control systems, should be developed. The force applied of the wire, of the tension of the wire that being pulled will be continuously monitored through a screen. This is important in order to achieve the quality and required specification of the unit. The sensor will sense the forces occurred and data will be transmitted to programs, which then will be compared to the pre-set tension. This feedback will drives the motor in required speed, controlled by the previous developed PID-System.

To reduce component size make the design engineers stay under constant pressure. While reducing the size, they must keep the performance or the function remain same or better. In the toroid development, most developers prefer to use the application of one-single layer of wire toroid, which nearly achieve their ideal performance.

2.9 ANGLE OF WINDING COILS

From a journal wrote by L. Zu, S. Koussios and A. Beukers, a toroid can be described as a bent, endless cylinder that saves on the need for material in the end caps. It was structurally efficient as a cylinder. Research has been devoted to the winding of toroidal structures, and mostly limited to the design of circular toroid (Lei Zu et al., 2009) presented an optimization method for non-geodetically overwound toroid and developed a CAD system for their design and production. (Li et al. 2002) outlined a full mathematical approach to the design of overwound toroidal vessels using a membrane shell theory, considering the load-bearing capability of the wound layer and its interaction with the metallic liner. (Jiang et al., 2010) developed a novel winder for producing toroidal pressure vessels, based on the optimal design of the corresponding winding patterns. The design of filament-wound toroid must take full account of the stress field as well as the material properties. Constraints imposed by the manufacturing process need to be respected, and the geometry that may restrict the structural efficiency must be properly determined. One of the shortcomings of the application of circular cross sections to toroid is that the tensile strength of the filaments cannot be completely utilized, because the structural efficiency of a toroid is entirely governed by the cross-sectional shape. Previous investigations merely considered the architecture of reinforcement layers, but overlooked the design of adapted cross-sectional shapes (i.e. meridian profiles) for toroid. It is thus desirable to obtain the most efficient cross-sectional shapes for these structures. A new possibility to improve the performance of toroidal vessels has been offered by (Koussios et al., 2010) in which a novel configuration combining isotensoids with toroid is developed. In this paper we outline a design-oriented method for determining the cross-sectional shapes of isotensoid toroid under internal pressure and axial load. First, the minimum strain energy criterion is used to determine the optimality relation for the winding angles and shell stresses of a general laminate, in order to maximize the load bearing capacity of such structures. Then, with the aid of the netting theory and geodesic winding law, the determination for the cross-sectional shapes of isotensoidal toroid is carried out to obtain constant fiber stress throughout the whole structure, taking into account the laminate thickness build-up along the meridional direction. The influence of the theoretically required axial load on the isotensoid meridian shape to close it is also evaluated. Lastly, the