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PREPARATION OF A MEASUREMENT-GUIDELINE FOR THE COMPONENTS OF ELECTRIC MOTORS FOR THE SUPPLIER

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TIIVISTELMÄ

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Tämä opinnäytetyö tehtiin ABB Oy:n IEC LV Motors -yksikön laatuosastolle. Tämän opinnäytetyön tarkoituksena oli luoda toimittajalle mittausohje sähkömoottorin eri komponenteille. Opinnäytetyössä tarkasteltiin myös erilaisia menetelmiä, joilla komponentteja mitataan koordinaattimittauskoneella. Opinnäytetyön tavoitteena oli myös arvioida mahdollisia virheitä mittausprosessissa ja tutkia erilaisia käytettyjä menetelmiä.

Opinnäytetyö keskittyy eri toimittajilta toimitettujen koneistettujen valurautaosien mittauksiin. Tutkittavat osat sisältävät erikokoisia staattorirunkoja, suojakilpiä sekä erilaisia laakerikomponentteja.

Mittaustesteillä selvitettiin nykyisin käytössä olevien mittauskäytäntöjen eroja. Näihin testeihin kuuluvat geometristen toleranssien mittaukset, sylinterin muodostaminen tai yhden ympyrän ottaminen, sekä mittauspisteiden määrän vaikuttaminen tuloksiin.

Avainsanat laadunvarmistus, laatu, ohjekirjat, koordinaatiomittaus

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ABSTRACT

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This thesis was created for quality department at ABB Oy, IEC LV Motors unit. The purpose of this thesis was to create a measurement guideline for the different components of the electric motor for the supplier. This thesis also examined the different methods used to measure the components using coordinate measuring machine. The aim of the thesis was also to evaluate the possible errors in measurement process and study the different methods used.

The thesis focuses on the measurements of the different machined cast iron parts that are delivered from different suppliers. The examined parts include different sizes of stator frames, D-and N-end shields, and different bearing components.

Measurement tests were made to study the differences in measurement practices that are currently being used. These tests include measurements of geometrical tolerances, forming a cylinder or taking a single circle and differences that come from the amount of measurement points taken from the measured feature.

Keywords	Quality assurance, quality, guidelines, and coordinate measuring

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ABBREVATIONS AND TERMS

ABB	Asea Brown Boveri
CMM	Coordinate Measuring Machine
D-End	Drive end of the motor
N-End	Non drive end of the motor
SPC	Statistical Process Control
ISO	International standard organization

1 INTRODUCTION

The purpose of this thesis is to create measurement guidelines for the different components of electric motors. These guidelines are primarily intended for the suppliers of the various components. Currently there are no specific guidelines on how each component is measured using a coordinate measuring machine. The aim is to develop guides that specify the features that are measured from the components and what methods are used.

Additionally, this thesis also aims to examine the measurement practises used in both factories at the IEC LV Motors division Vaasa and compare them. The aim of the thesis is also to evaluate possible errors made in measurement process and study different methods used.

1.1 Scope of the Thesis

The thesis focuses on measurements of cast iron parts of the motor. Measurement instructions are made for different sizes and models of parts of the motors that are produced in IEC LV motors Vaasa.

The components that instructions are made for include both D and N-end shields, Frames, and different bearing components. For the other components such as terminal box frames and other cast iron parts, general guidelines are made.

1.2 Company Presentation

ABB is a multinational corporation which operates in over 100 countries and globally employs over 105 000 personnel. ABB is one of the world leaders in automation and electrification technology. The company specializes in four different business areas that are electrification, motion, process automation and robotics & discreet automation.[1]

ABB was formed in 1988 when Swedish ASEA (Allmänna Svenska Elektriska AB) and Swiss BBC (Brown, Boveri & Cie) merged and started a new company with its headquarters in Zurich. Both ASEA and BBC were amongst the leading electrical engineering companies in the world.[2]

ABB operates in approximately 20 locations in Finland and employs approximately 5 000 personnel. The main factories in Finland are in Helsinki, Vaasa, Hamina and Porvoo. Currently ABB is one of the biggest industrial employers in Finland.

The factories in Helsinki produce robots, electrical motors, generators, frequency converters, CPM-energy management systems and paper machine drive solutions. Another bigger factory concentration in Vaasa focuses on electrical motors, low-voltage products and systems, total project management of the process industry, power generation systems, electricity transmission and distribution systems. Smaller factories in Porvoo and Hamina produce electrical installation products and Azipod®-rudder propeller systems.[3]

The IEC LV Motors division in Vaasa focuses on producing and developing high efficiency electrical motors. Motors made in Vaasa are IEC low voltage motors suitable for many different industries and applications worldwide. The factories in Vaasa have been producing low voltage motors since 1944. Currently IEC LV Motors division employs approximately 600 personnel in Vaasa.[4]

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[1] ABB, about ABB accessed 18.3.2023 https://global.abb/group/en/about
[2] ABB, about, history ABB accessed 18.3.2023https://global.abb/group/en/about/history
[3] ABB, ABB lyhyesti, suomessa accessed 8.3.2023 https://new.abb.com/fi/abb-lyhyesti/suomessa
[4]

2 THEORY

2.1 Electric Motor

Electric motors are key components in many different applications. There are many different types of electrical motors, from small-size motors that power electrical watches to industrially used large motors that power heavy machinery. Efficiency, reliability and simple design are some of the advantages of electric motors.

The electric motor converts electricity to mechanical energy. The principle of the electric motor is the interaction of magnetic field and electrical current that is driven into a coil winding, which generates torque into the motor shaft. Electric motors can be powered by either AC or DC sources. AC sources for example, can be electric generators, power grids and inverters. DC sources can be batteries and rectifiers.[5]

2.1.1 Squirrel Cage Induction Motor

Squirrel cage induction motors are electric motors that use AC power sources. Current is driven to the stator inside the motor which forms a rotating magnetic field. The magnetic rotor follows the magnetic field caused by the rotation of stator and causes the rotor to turn. Because the rotor is magnetized, there is no need to use carbon brushes or metal brushes inside the motor.

This motor type is popular because of its simplicity, low cost, low maintenance and sturdy construction. Induction motors require low maintenance because

[5] Engineerspost, types of electric motors, accessed 20.3.2023 https://www.theengineerspost.com/types-of-electric-motors/

there are no brushes that need to be maintained and the only parts that experience a lot of wear are the bearings inside the motor.[6]

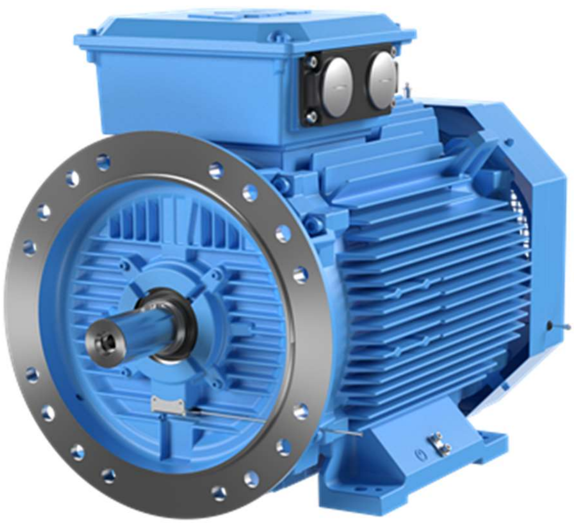

Figure 1. 3-Phase squirrel cage motor M3BP 250SMC 8 /6/[7]

2.1.2 Construction of Squirrel Cage Induction Motor

The largest component is the frame of the motor. Depending on the engine mounting style, there may be no feet on the frame. The frame houses the motor's

[6] Engineerspost, types of electric motors, accessed 20.3.2023 https://www.theengineerspost.com/types-of-electric-motors/
[7] ABB, products, accessed 20.3.2023 https://new.abb.com/products/3GBP254230-HSG/3gbp254230-hsg

stator, which is pressed inside. The shaft is fitted inside the rotor core, which spins within the stator when current is applied. The shaft and rotor core together form the rotor of the motor. Between the rotor and the stator, there is a small air gap. The size of the air gap is designed to be as small as possible. The end shields are fitted to both D- and N-Ends of the frame, with bearings installed inside the end shields to support the rotating shaft.

Power source is connected to the terminals that are located inside terminal box of the motor which can be on either the top of the frame or on the side of the frame. A cooling fan is installed to the N-End and is rotated by the shaft. The cooling fan is also protected by a fan cover.

2.1.3 Motor Sizes and Mounting Arrangements

Sizes of the motors produced by ABB are determined by the height of the shaft from the feet of the frame. The height is measured from the bottom of the feet to the middle of the rotor. If the motor frame does not have feet, the size is still determined by the model that does have feet. The IEC LV Motors division in Vaasa produces motors that range in size from 56 to 500.

ABB supplies motors that have foot mounting, flange mounting or the combination of both. The flange mounting is made possible with flange type D-end shields. There are six different main mounting arrangements that include another six mounting arrangements, so in total there are 36 different mounting arrangements.[8]

[8] ABB, low voltage process performance motors, accessed 5.5.2023https://search.abb.com/library/Download.aspx?DocumentID=9AKK105944&Lan-guageCode=en&DocumentPartId=&Action=Launch

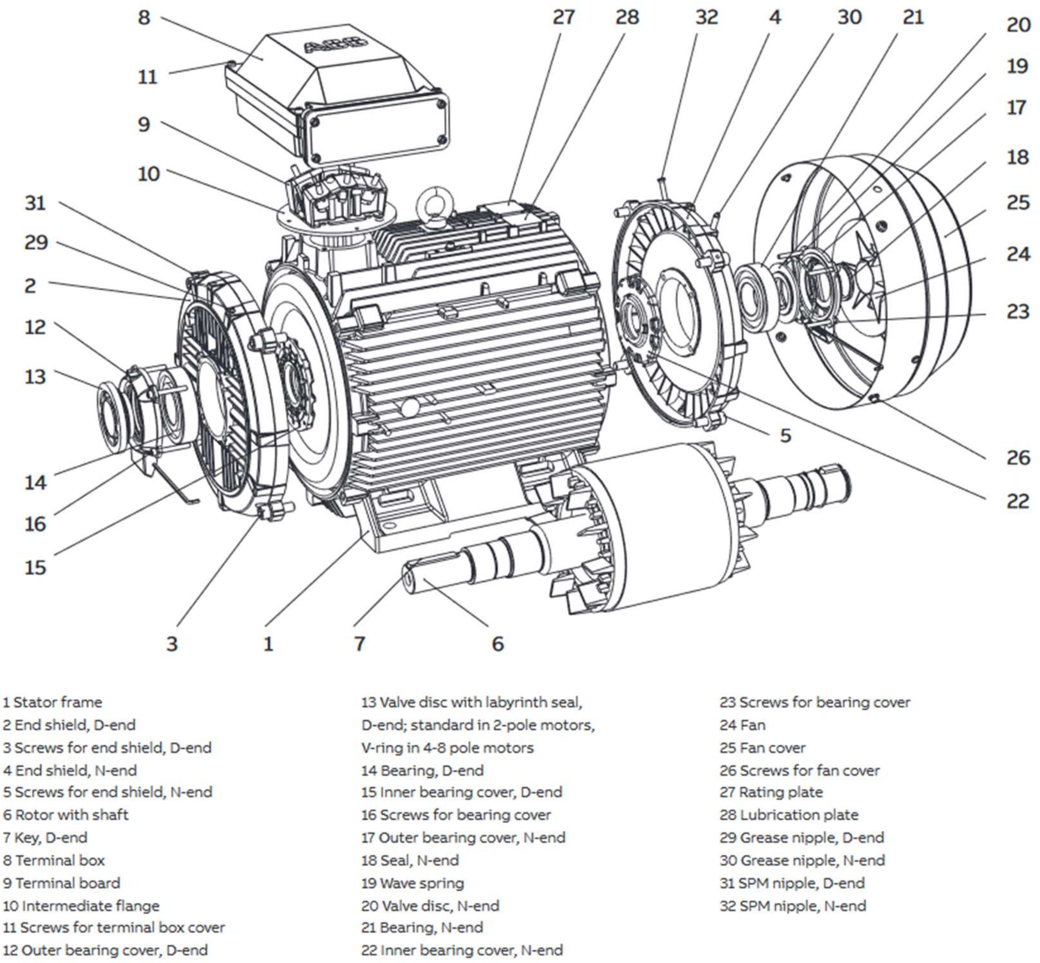

Figure 2. Construction view of frame size 315 motor[9]

[9] ABB, low voltage process performance motors, accessed 5.5.2023https://search.abb.com/library/Download.aspx?DocumentID=9AKK105944&Lan-guageCode=en&DocumentPartId=&Action=Launch

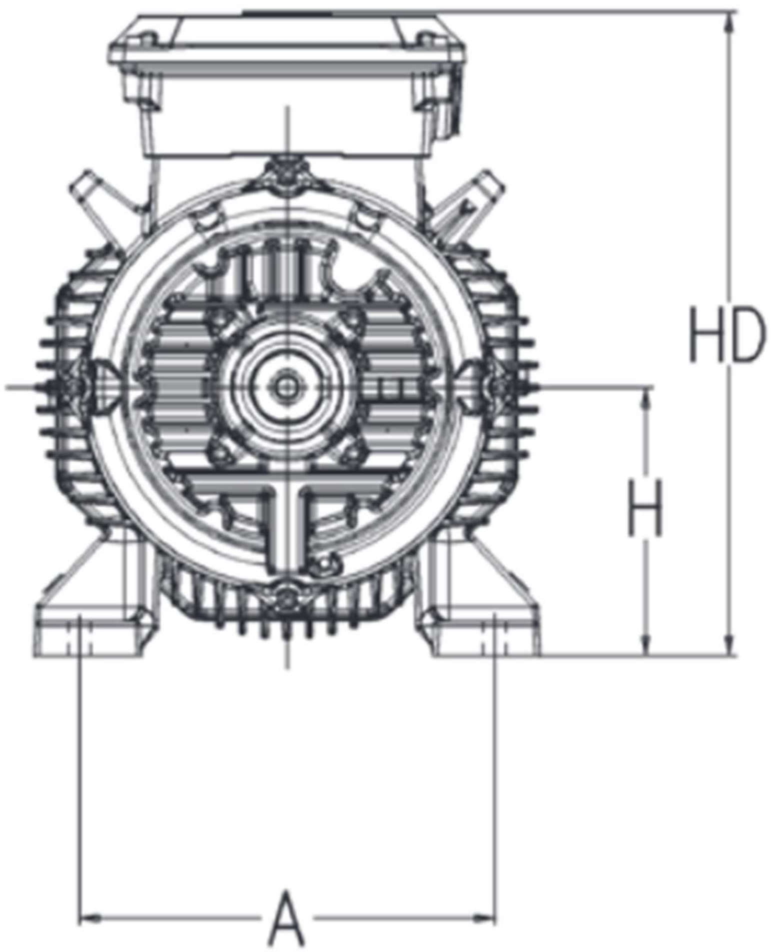

Figure 3. Dimension H represents the motor size[10]

[10] ABB, low voltage process performance motors, accessed 5.5.2023https://search.abb.com/library/Download.aspx?DocumentID=9AKK105944&Lan-guageCode=en&DocumentPartId=&Action=Launch

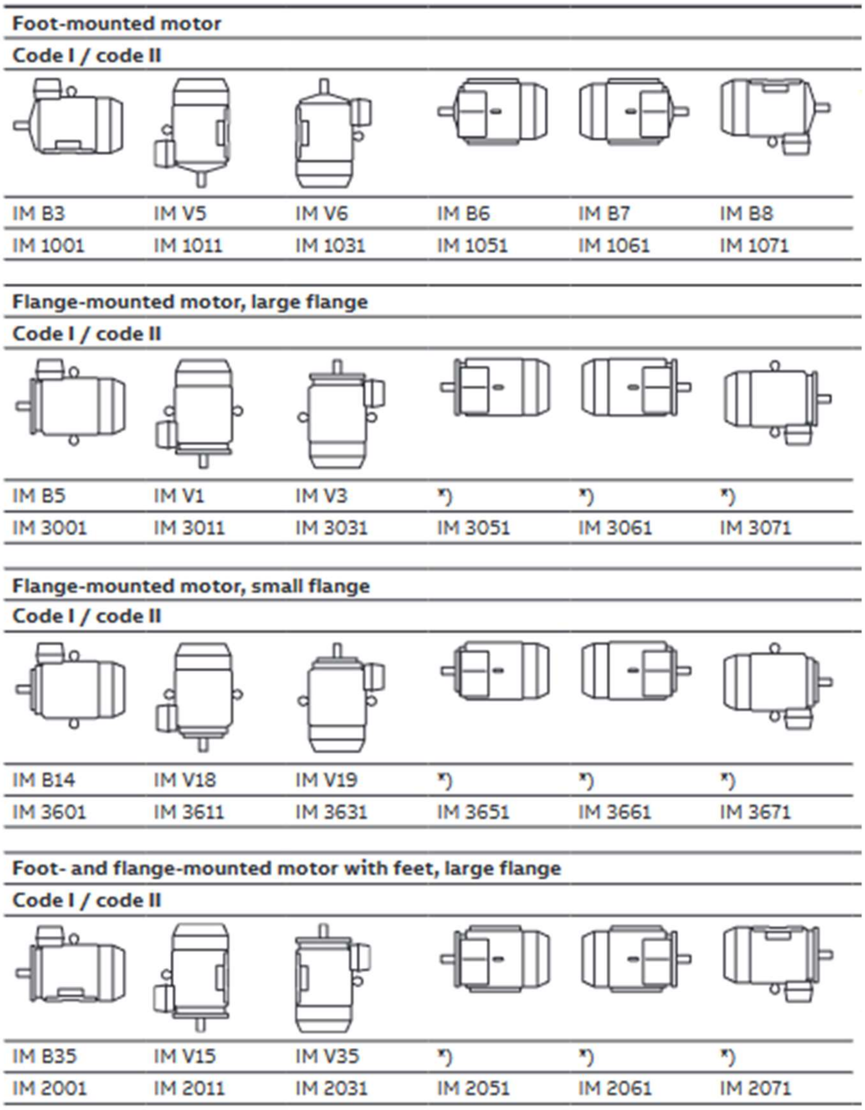

Figure 4. Examples of different mounting arrangements[11]

2.2 Coordinate Measuring Machine

The coordinate measuring machine (CMM) is a measuring machine which uses points determined in the coordinate system to measure geometric and physical dimensions of a part. The CMM uses three axis X, Y and Z to build the coordinate system, the locations of the axis are determined by using accurate measuring rods. The CMM uses either a touch probe to determine the points on the part, or a non-contact model that uses either lasers or cameras. Points gathered by CMM are transferred to the computer software that calculates wanted measurements and displays them.

The CMM measures the actual shape of the part and compares it against the desired shape. An advantage of using CMM is that they are capable of measuring parts with a high accuracy that are otherwise difficult and slow to measure with other measuring means.[12]

2.2.1 Operating CMM

Measuring with the CMM has become easier with the development of more user-friendly software. To obtain reliable results, the operator of the machine must have sufficient training, as well as understanding of CMM measuring, as most commonly uncertainties in measuring results comes from the operator.

Measuring with the CMM requires that the operator develops a measuring program, which uses the points gathered from the required features on the part to calculate measurements. The operator needs to select correct measurement strategies such as which probe to use, specific measurement routines and algorithms. Logics and calculations need to be made to the program to get the wanted measurement results and tolerancing calculations. Once the program is ready and thoroughly tested to ensure accuracy and reliability, it is ready to be used. Well-made programs can be used for a long time if the specifications of measured part do not change. [13]

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[11] ABB, low voltage process performance motors, accessed 5.5.2023https://search.abb.com/library/Download.aspx?DocumentID=9AKK105944&Lan-guageCode=en&DocumentPartId=&Action=Launch
[12] Hocken, Robert J. Pereira, Paulo H. 2012, s 58-61. Coordinate Measuring Machines and Systems, CRC Press
[13] Hocken, Robert J. Pereira, Paulo H. 2012, s 82-91. Coordinate Measuring Machines and Systems, CRC Press

2.2.2 Fixturing and Aligning Part

The measured part to be measured needs to be fixtured to the CMM table rigidly enough that the part does not move during the measurement process. Forces that the CMM introduces to the part are low so the fixtures keeping the part in place do not have to be as big and restraining as the fixtures used in manufacturing processes, also heavy parts do not necessarily need fixturing. It is also important to fixture the work part in the way that all the required features can be measured without a need to refixture the work part, as the refixturing increases time spent measuring and possibly increases uncertainty in measurement results.[14]

Aligning the work part means creating a coordinate system on the work part. Alignment is created by taking certain points from the part with the CMM. By aligning, the work coordinate can be moved to the work part from the coordinate system of the machine. Using the coordinate system created with alignment removes the measurement uncertainties that may come from part placement and fixturing on the table, as the CMM now knows the exact placement and orientation of the part on the measuring table.[15]

2.2.3 Measurement Uncertainty

Uncertainties in CMM measuring come from many sources and they vary highly depending on the task that is performed with the CMM and the environment that the task is performed in. The Operator also needs to choose the right measuring

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[14] Hocken, Robert J. Pereira, Paulo H. 2012, s 86-88 Coordinate Measuring Machines and Systems, CRC Press

[15] Wasyresearch, part alignment procedure on coordinatemeasuringmachine, cmm for dimensional and geometrical measurements, accessed 30.3.2023 https://www.wasyresearch.com/part-alignment-procedure-on-coordinate-measuring-machine-cmm-for-dimensional-and-geometrical-measurements

methodologies that lower the possible uncertainties. CMM uncertainties can be divided to five categories;

- hardware
- workpiece
- sampling strategy
- fitting and evaluation algorithms
- extrinsic factors

The uncertainty that comes from the CMM itself, are geometric errors that can be calculated using formula:

- $MPEe = a+b*L$.

The formula comes from the ISO standards. MPEe is the maximum permissible error, a and b are values that are supplied by the manufacturer of the CMML is the length or largest distance to the datum that is being evaluated.[16]

The number of points taken from the infinite number of points that are in measured feature, create a sampling uncertainty. As the number of points increases, the amount of sampling uncertainty decreases. The sampling error can be calculated using formula:

- $u=\sigma pc/\sqrt{(n-x)}$

Where σpc is the point coordinate error, n is the number of points taken from the feature and x is the minimum number of points required to define the feature. The

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[16] Hocken, Robert J. Pereira, Paulo H. 2012, s 379 Coordinate Measuring Machines and Systems, CRC Press

minimum number of points taken to define line is two, for plane and circle three, for sphere four and five for cylinder.[17]

Measuring uncertainty coming from the temperature of measuring environment, CMM and measured part could be avoided if the temperature of all three was always 20°C. In practice, this is not possible and there are always uncertainties coming from the temperatures of all three. In most cases the temperatures contribute the most to the measurement uncertainty.

The CMM measures the temperatures and measuring software calculates the uncertainties coming from the thermal effects. The measuring software has temperature compensations, which allows the measuring machines to be used accurately in range of 18 - 22°C and avoiding uncertainties coming from the thermal effects.[18]

To avoid any unnecessary uncertainties, the operator of the CMM needs to have good understanding of the measurement progress and the measurement machine needs to be calibrated and verified often enough.

[17] Hocken, Robert J. Pereira, Paulo H. 2012, s 378 Coordinate Measuring Machines and Systems, CRC Press
[18] Hocken, Robert J. Pereira, Paulo H. 2012, s 379 Coordinate Measuring Machines and Systems, CRC Press

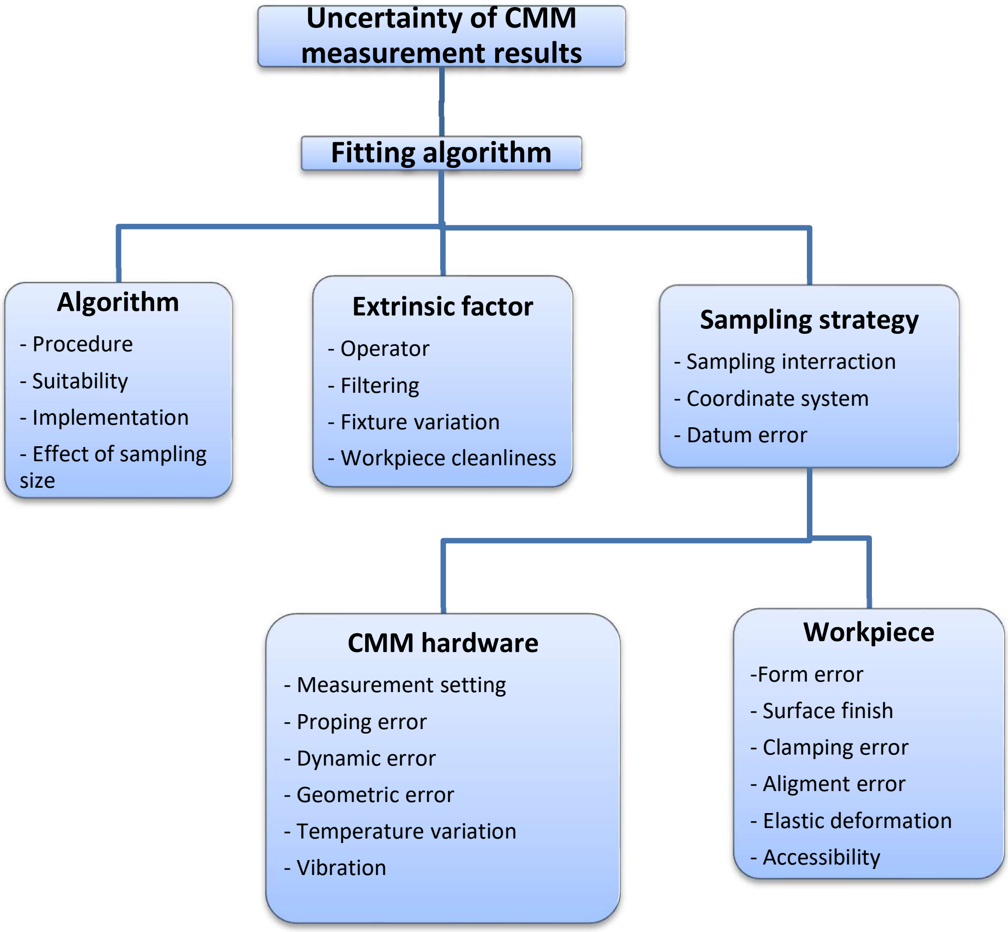

Figure 5. Table of error components that lead to uncertainties

2.2.4 Technical Data

Currently there are two CMM systems in use at ABB IEC LV motors Vaasa. Both machines are Dea Global Performance bridge type touch probe systems. The maximum permissible error of indication for size measurement (MPEE) while operating in temperatures 18-22°C according to ISO 10360, for both systems can be calculated using the formula:

- MPEE = 1.5+3.0*L/100

MPEE is given microns and L is the measured length in millimeters.

DEA, Global performance 09.15.08 located in the KK-factory

- Range: X:900mm Y:1500mm Z:800mm
- Registration year: 2011

DEA, Global performance 12.30.10 located in the MM-factory

- Range: X:1200mm Y:3000mm Z:1000mm
- Registration year: 2006

Both factories have quality inspection areas where the machines are located, which the areas are well ventilated and climate controlled. Calibration interval is 12 months for both systems.

2.3 Mechanical Measuring Instruments

Measuring with handheld instruments can be a lot faster than measuring with the CMM, but it is impossible to reach the same degree of accuracy in results. Handheld measuring is still important because some parts do not require measurements done with the CMM, as tolerances are not so strict on some parts.

Handheld measuring is often seen simple, but in reality the operator who does the measurements has to have a good understanding of measuring theory to get good measurement results.

2.3.1 Measurement Uncertainty Factors with Handheld Instruments

Several factors need to be addressed while making the measurements to get the best results. Environmental factors such as temperature and humidity can expand and contract both the measured piece and the measuring device that is in use. The operator must check the measuring tool that it is calibrated, clean and not damaged before the taking the measurements.

Correct measuring instruments and measuring methods need to be chosen to get the wanted measurements. All taken measurements need to be done in way that they are consistent and can be taken multiple times and yielding the same results.

2.4 Geometrical Tolerances

Geometrical tolerances are used to specify geometric features on parts such as, size, shape, orientation, and locations. The use of geometric tolerances are necessary to ensure that parts fit together, and assemblies are functional. The values of geometrical tolerances need to be well designed, because too strict tolerances on parts that are produced can cause the part to become unnecessary hard and expensive to make. Well-designed geometrical tolerances also lower assembly failures and reduces part reject rate in quality control.

Quality inspectors who measure the tolerances also must understand how they work and how they are meant to be measured. Choosing the right base datums are also important because, some tolerances are referenced to those datums. Geometric tolerances are presented in mechanical drawings by feature control frame. All symbols and meanings are presented in Table 1 below.[19]

[19] Formlabs, GDT, geometric dimensioning and tolerancing, accessed 29.3.2023 https://formlabs.com/eu/blog/gdt-geometric-dimensioning-and-tolerancing/

Table 1. Geometrical tolerance symbols and meanings.[20]

TYPE OF TOLERANCE	CHARACTERISTIC	SYMBOL
FORM	STRAIGHTNESS	⏤
	FLATNESS	▱
	CIRCULARITY	○
	CYLINDRICITY	⌭
PROFILE	PROFILE OF A LINE	⌒
	PROFILE OF A SURFACE	⌓
ORIENTATION	ANGULARITY	∠
	PERPENDICULARITY	⊥
	PARALLELISM	//
LOCATION	POSITION	⌖
	CONCENTRICITY	◎
	SYMMETRY	⌯
RUNOUT	CIRCULAR RUNOUT	↗
	TOTAL RUNOUT	⌰

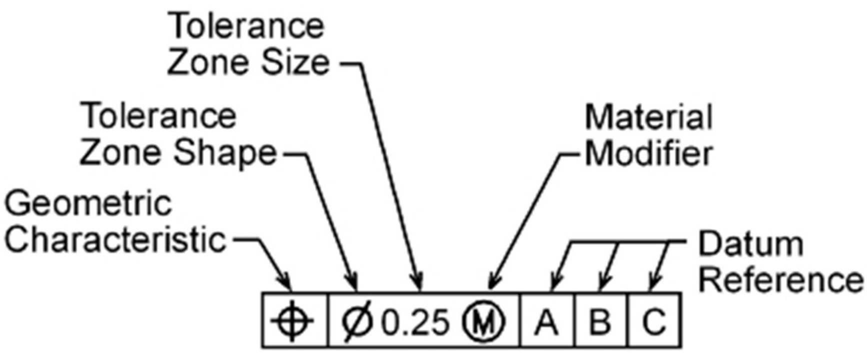

Figure 6. Feature control frame explained.[21]

[20] Faro, what is gdt, accessed 30.3.2023 https://www.faro.com/en/Resource-Library/Article/what-is-gdt

2.4.1 Measuring Geometrical Tolerances

Geometrical tolerances are best measured with the CMM. Some features can be measured with handheld devices such as gauge and height blocks. When measuring geometrical tolerances with CMM, it is important that the operator who does the measuring program chooses the correct planes and features and that they are being referenced to the correct datums. When measuring for example circularity or flatness, it is important to choose enough points on the measured part that the whole feature is measured correctly.

Geometrical tolerances of the parts should always be measured in the way that they are represented in the mechanical drawings. Different measurement methods can be used to measure the geometrical tolerances, but before they are used, it is important that the different methods are approved and represents the wanted measurements correctly.

[21] Engineeringessentials, gdt, referenced 30.3.2023 http://www.engineeringessentials.com/gdt/links/fcf.htm

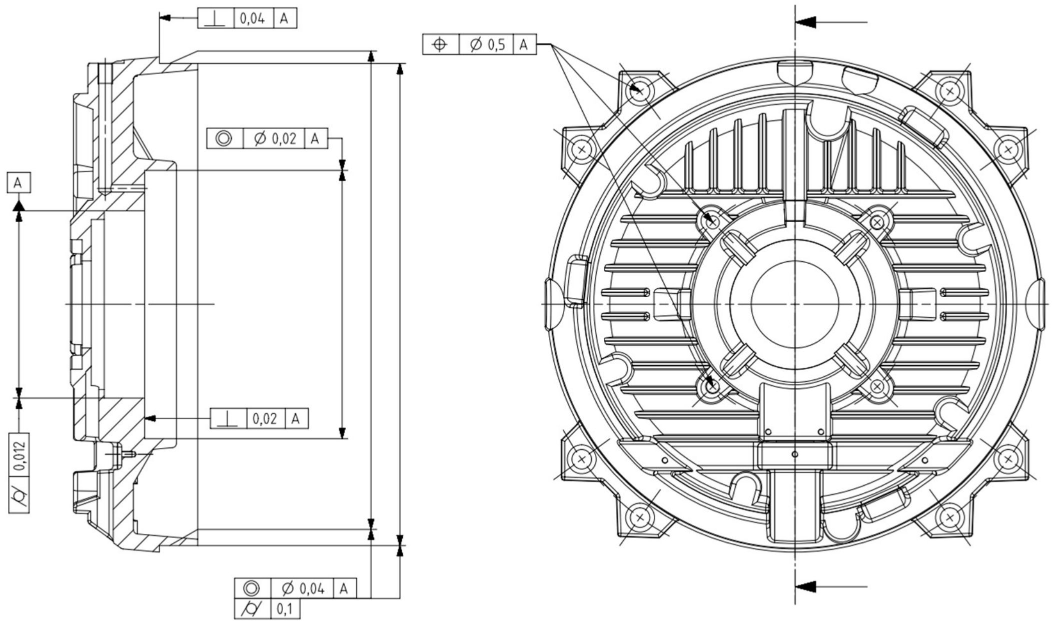

Figure 7. Geometrical tolerances used in D-end shield

2.5 SPC in Quality Control

With large production values it becomes hard to control the quality characteristics of every single product. Good SPC collects data which is then inserted to different SPC tools that are different types of charts and diagrams. With SPC quality control methods it possible to take samples that are measured thoroughly instead of measuring every part.

SPC tools evaluates the process and makes it cost-effective and efficient. The aims of SPC is to understand current process and its specification limits, ensure stable processes and monitor quality of ongoing process and allow improvements and corrective actions to be made.[22]

[22] Capvidia, spc guide, accessed 3.4.2023 https://www.capvidia.com/blog/spc-guide

2.5.1 Variations in SPC Quality Control

Variations can be divided into two categories, common cause variations and special cause variations. Common cause variations should be random, but if a continuous pattern can be recognised, the cause of that variation needs to be investigated. [23]

Examples of common cause variations:

- environmental conditions such as temperature and humidity
- wear on used equipment and tools
- measurement variations
- operators work variations
- change of material properties

Examples of special cause variations:

- error in machinery or broken tools
- change in measurement system
- failed controller tool
- faulty calibration in tools
- mistake made by operator
- shift in process

2.5.2 Sampling in SPC

When speaking of all the possible parts or elements in the process, they are referenced as population. A sample term is used when talking only about a specific part of that population. In quality control, populations can be so big that measuring or

[23] Capvidia, spc guide, accessed 3.4.2023 https://www.capvidia.com/blog/spc-guide

checking the whole population is not possible, as it becomes too cost ineffective. With large populations, sampling becomes necessary to still monitor the variations in the process. Samples need to be taken frequently enough that the changes in the process can be detected, but the sample frequency should not be too fast, that measured samples do not display any variation.

Choosing the sample from the whole population needs to be done at random as the main point of the sampling is that it represents the population. In random sampling every part has the same chance to be chosen.[24]

[24] Infinityqs, SPC-101, populations and sampling accessed 3.4.2023 https://www.infinityqs.com/statistical-process-control/spc-101/populations-and-sampling

3 MEASURING PROCESS AT QUALITY INSPECTION

Currently from all the machined components that come from suppliers, 5% is measured at quality inspection. If the number of the incoming components is low, at least three pieces need to be inspected. The inspection includes visual inspection and measurement of the components.

The measurements are made either by using a CMM or handheld measurement tools. After the inspection of the component the whole batch that is delivered is either accepted and the components are send to storage to be used or rejected. If the batch is rejected, the quality engineer is notified, and they make the required follow-up measures.

3.1.1 CMM Measurement Process

If the measured part is new and it has not been measured before, a new measuring program needs to be developed. If the new part is similar to previously measured parts, it is possible to develop the program using the existing programs for similar components. When measuring parts with existing programs, it is important to always check for possible changes in the mechanical drawings and edit the measuring program if necessary.

When developing a whole new program, the parts to be measured, measuring methods, measurements in drawings and tolerances need to be thoroughly assessed.

Parts are usually dirty, so they need to be wiped clean with a lint-free cloth and cleaning spray. The temperature of the parts need to be checked as well, as some parts can come straight from transit to quality inspection. Especially in winter and summer times parts can be hot or cold when they come to quality inspection.

4 MEASUREMENT GUIDELINES

All the measurement guidelines are made based on the measurement programs that are currently being used at both MM and KK plants. Components included in guidelines are different sizes of motor frames, D and N-end shields, flange end shields and bearing covers.

Components measured at the KK-plant range from size 56 to 250 motors. Larger components are measured at the MM-plant.

4.1 Preparation

At first it was necessary to consider what is important and what to include in the guidelines and how to depict them so that they are easy to understand even if the reader does not have a lot of expertise in CMM measuring. The style of guidelines also had to be made in way a that they are easy and clear to read.

The guidelines include which features are measured with the CMM in the component and if there are some specific measuring techniques that are used in the measuring process. The number of points taken and if the feature is measured with multiple point levels is stated in the guides. In the diameter measurements, the position of the point levels is stated in the guides, for example at which distance the stator hole of the frame is measured from the face plane. Height differences between point levels is also given. To present clearly where the measuring points are, a figure was made showing each point and in diameter measurements, a point levels are shown.

The number of points taken, and point levels taken from the measured feature is shown in a table to make it clearer than just writing it. The figure that shows the point locations and point levels is added to each guide. Points and point levels in the figures are not exactly in correct positions but they show roughly where they are taken from.

Table 2. Number of points and levels taken from size 200 end shield

LOCATION	MEASURING POINTS	POINT LEVELS
Bearing housing	16	2
Bearing housing steering	16	2
Steering large	15	1
Steering small	16	2
Bearing housing base plane	8	-
Face plane	4	-

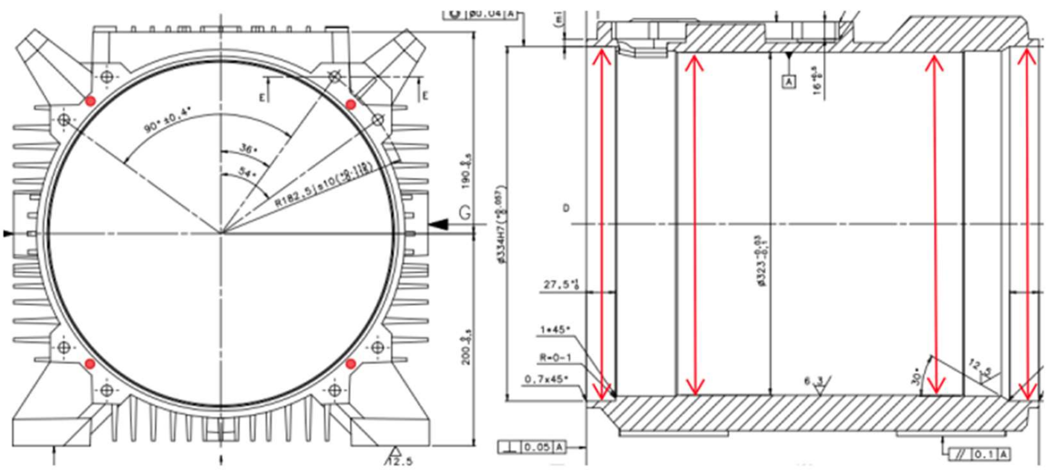

Figure 8. Measuring points and levels in size 200 frame

4.1.1 Creation of the Guidelines

All the guidelines are made using already existing measurement programs that are being used currently at both plants. It was not necessary to run each program as it is possible to review programs using the CMM software PC-DIMS that is in use. PC-DMIS software shows the features that are measured and displays the number of points that are taken from each feature.

With some components, the same type of measurement program was used between different sizes, so it was not necessary to make a multiple guidelines for them. The Measurement programs also included components that are not measured with the CMM anymore, so creating a guideline for them was not needed.

4.1.2 Differences between the Programs

There were some differences in practices used in the making of the programs between the plants, but the different ways to make the programs do not impact the measurement results. The way that the programs are made is decided by the operator and usually the used methods, are the those that the operator feels the most comfortable with.

Some differences in the measurements of the components were found. One of the differences is the way that steering is measured in the stator frames and end shields. In some components it was measured with forming a two-level cylinder from the feature and in others with taking one level circle around it. In the stator frames the one circle around the steering was the most common way of measuring, but in end shields the cylinder method and one circle method was used more equally.

The number of points taken from the measured features was different in many components. In some larger components fever points were taken than from the smaller size components. There is no clear increase in the number of points taken from the measured features, as the components increase in size.

When measuring the geometrical tolerances in the stator frames, two different methods were used, in larger frames concentricity between the steering and stator hole is measured with comparing the steering to circle taken from the stator hole, D-end steering is compared to the circle taken from the D-end of the stator hole. The same method is used for the N-end. In smaller frames concentricity is measured by comparing the steering and a cylinder created from a taking point from both ends of the motor. Perpendicularity is measured between the end planes and comparing them to a line created that goes through the D- and N-end steering. In smaller frames perpendicularity is compared between a plane and cylinder formed the inside stator hole.

5 MEASUREMENT TESTS

All the tests were made with the measuring size 225 stator frame. This size was chosen as it is one of largest motor sizes that it measured at the KK-plant. The measurements were made with CMM. Different tests performed were based upon the differences between the measuring programs that were found when making the guidelines.

These tests include comparing the number of points taken from features, difference of forming a cylinder or measuring with just one circle and different ways to measure geometrical tolerances.

5.1 Comparing the Number of Points Taken from Stator Hole

Tests were made by using the measurement program that was already used to measure the component, the only change to program was the number of points taken from the stator hole. The number of points taken were 3, 5, 9, 13, and 17.

Table 3. Measurement results with different number of points

Feature	3 Points	5 points	9 points	13 points	17 points
stator hole 360 (-0.030 / -0.100)	-0,084	-0,083	-0,086	-0,081	-0,081
Concen. D-steering to stator hole	0,113	0,099	0,069	0,058	0,058
Concen. N-steering to stator hole	0,058	0,049	0,029	0,014	0,015
Perpend. D-plane to stator hole	0,020	0,032	0,015	0,015	0,016

From the results 3 and 5 points from the stator hole is not enough as the geometrical tolerance results are significantly larger than in 9-, 13- and 17-point measurements. When measuring the diameter of the stator hole, the number of points taken did not change the results more than couple of thousands of a millimetre.

As the test conditions are not perfect, a change of few thousands of a millimetre is expected even if measuring the same part with exactly the same program multiple times.

Currently the part is measured with taking nine points from the stator hole. The test results suggest that it would be beneficial to take more measurement points, as the more points taken, the more trustworthy results. Also, many different guidelines suggest the use of prime numbers in the number of measurement points taken in diameter measurement.

5.2 Forming a Cylinder to Steering of the Stator Frame

Currently some stator frames are measured by forming a two-level cylinder to steering in both ends of the motor. A more common way is just taking a single level of points from the steering and not forming a cylinder. In these tests the number of points taken remained the same on the stator hole, but a two-level cylinder was formed to both D- and N-End steering. In these measurement tests the D- and N-end steering was measured with taking a nine-point circle, two level cylinder with nine points in each level and three level cylinder with nine points on each level. Three stator frames were measured.

Table 4. Measurement results with single circle and cylinders

Feature	Part 1	Part 2	Part 3
D-steering 376 (+0,057/0) circle	0,016	0,002	-0,003
D-steering 376 (+0,057/0) cylinder 2 levels	0,015	-0,001	-0,005
D-steering 376 (+0,057/0) cylinder 3 levels	0,018	0,002	-0,001
N-steering 376 (+0,057/0) circle	0,019	0,012	0,009
N-steering 376 (+0,057/0) Cylinder 2 levels	0,014	0,003	0,005
N-steering 376 (+0,057/0) Cylinder 3 levels	0,018	0,007	0,009

In diameter measurements, the results did not display a significant change between the measurement methods. One exception to this is N-steering in part two, where one circle gives result 0,012 and cylinder with two levels gives 0,003.

Table 5. Concentration measurement results with circle and cylinder

Feature	Part 1	Part 2	Part 3
Concen. D-steering to stator (circle)	0,034	0,022	0,014
Concen. D-steering to stator (cylinder 2 levels)	0,039	0,020	0,013
Concen. D-steering to stator (cylinder 3 levels)	0,039	0,020	0,012
Concen. N-steering to stator (circle)	0,037	0,043	0,018
Concen. N-steering to stator (cylinder 2 levels)	0,035	0,042	0,026
Concen. N-steering to stator (cylinder 3 levels)	0,035	0,042	0,026

When measuring the concentricity of steering to the stator hole which is formed with taking nine points from both ends of the motor and forming a cylinder, results did not change between the method used to measure the steering. The results show that it does not matter if a cylinder is formed with three or two levels, this can be because the height of the steering is only 27.5 mm. If the height was larger, there could be differences in three- and two-level cylinders. These measurement tests suggests that there is no big difference between the measurements where steering is measured with just taking a single circle around it compared to forming a two or three level cylinder.

5.3 Increasing the Number of Points in Plane of the Stator Frame

Currently in some stator frames, only four measurement points are taken from the end planes of the frame. The points are taken from four areas near where the end shield connection drill holes are located. In this measurement test four points were added to the sides, top and bottom of the plane to see how the added points change the measured geometrical tolerances.

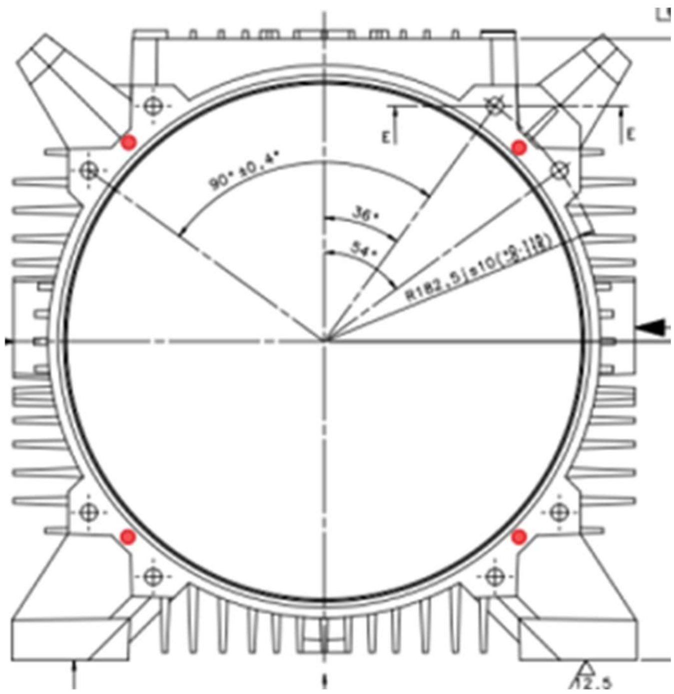

Table 6. Measurement results with taking four and eight points from plane

Feature	Part 1	Part 2	Part 3
Perpendicularity D-plane to stator (4 points)	0,040	0,069	0,051
Perpendicularity D-plane to stator (8 points)	0,043	0,064	0,057
Parallelism D-plane to N-plane (4 points)	0,035	0,025	0,016
Parallelism D-plane to N-plane (8 points)	0,045	0,048	0,025

Small changes in the results were detected when comparing the perpendicularity of the D-plane to the stator hole of the motor between four points taken to eight points taken. Parallelism between the planes changed a lot with adding four additional points to the planes. The results suggest that taking only four points from the planes is not enough as it does not guarantee that the whole plane is represented correctly in the measurements. Adding points to the planes presented one problem where, points had to be moved a bit between the measured parts, as casting tolerances allows the wall thickness to change, so that added points on the sides, top and bottom could miss the feature.

5.4 Comparing Concentricity and Perpendicularity Measuring Methods

This test compares the measurement results of concentricity and perpendicularity geometrical tolerances that are used in the measurements of the stator frames. Currently the concentricity of steering to the stator hole is measured using two different methods, comparing steering to a circle in the stator hole or comparing steering to a cylinder formed inside the stator hole. Perpendicularity is either measured by the comparing plane a to line created in the middle of both D- and N- end steering or by comparing the plane to a cylinder inside the stator hole.

Table 7. Concentricity measurement results

Feature	Part 1	Part 2	Part 3
Concen. D-steering to stator cylinder	0,034	0,022	0,014
Concen. D-steering to stator circle D-end	0,021	0,012	0,016
Concen. N-steering to stator cylinder	0,037	0,043	0,018
Concen. N-steering to stator circle N-end	0,024	0,019	0,017

The results show a difference in measuring methods when measuring concentricity. The method where steering is compared to a circle inside the stator hole is used when measuring larger components. For smaller components comparing to a cylinder is used.

Table 8. Perpendicularity measurement results

Feature	Part 1	Part 2	Part 3
Perpen. D-plane to stator cylinder	0,043	0,064	0,057
Perpen. D-plane to line	0,034	0,047	0,046

Measuring perpendicularity between the D-plane and a line yields better measurement results than comparing the plane to a stator cylinder. In larger components comparing the plane and line method is used to measure perpendicularity. Comparing the plane to stator cylinder method is used for smaller components.

6 CONCLUSION AND FURTHER DEVELOPMENT

The aim of this thesis was to create guidelines for different components used to produce electric motors and study different measurement practices used to measure the different components with the CMM. The thesis describes the preparation process of the guidelines and specifies the differences that were found between measurement methods.

Different measurement tests show that there are differences in measurement results when using different measurement methods. The tests also show that adding more points especially to the planes of the stator frame changes the measurement results. The tests where different the number of measurement points were taken from the stator hole of the stator frame, show that decreasing the number of points taken from the currently used nine points, drastically change the measured geometrical tolerances. Adding more points to the stator hole did not impact the results as much as decreasing them.

Some possible further developments are that measuring methods are studied more on different components and different sizes, to see especially how the size of measured feature effects the results. Based on made findings, guidelines and tests, a common way to measure the components at both plants could be developed, to remove the differences between the components and the plants. Adding a few more measuring points to the measuring programs would also benefit the measuring accuracy on some components. Some currently used measuring programs could also be modified, but the possible changes need to be discussed thoroughly between the quality inspectors and the quality engineers if they are needed.

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