Universidad Zaragoza
1542

Trabajo Fin de Grado

Integración de un Sistema de monitorización de condiciones en una turbina eólica de investigación

Integration of a Condition Monitoring System (CMS) in a research wind turbine

Autor/es

Paula Alonso Álvarez

Director/es

Michael Pagitsch
José Luis Santolaya Sáenz

INGENIERÍA DE DISEÑO Y FABRICACIÓN
2016

CWD Chair for Wind Power Drives | RWTH AACHEN UNIVERSITY

Bachelor Thesis

Integration eines Condition Monitoring System (CMS) in eine Forschungs-Windenergieanlage

Integration of a Condition Monitoring System (CMS) in a research wind turbine

Diese Arbeit wurde am Chair for Wind Power Drives vorgelegt von:
Paula Alonso, Frau
Matrikelnummer: 362712

Fakultätsinterner Betreuer: Univ.-Prof. Dipl.-Ing.Dennis Bosse
Betreuender wissenschaftlicher Mitarbeiter: Dipl.-Ing. Michael Pagitsch

August 23, 2016

Inhalt und Ergebnis dieser Arbeit sind ausschließlich zum internen Gebrauch bestimmt. Alle Urheberrechte liegen bei der RWTH Aachen. Ohne ausdrückliche Genehmigung des betreuenden Lehrstuhls ist es nicht gestattet, diese Arbeit oder Teile daraus an Dritte weiterzugeben.

Contents

Declaration **I**

List of Figures **III**

1 Introduction **1**

2 Condition Monitoring for Wind Turbine Optimization: Dynamic Load Monitor (DLM) **2**

2.1 DLM system applied to wind turbines 2

2.2 Active Torque Control (ATC) 3

3 Clarification of the task: installation and definition of requirements **5**

3.1 Requirements for the installation 5

4 Design of the structure for the first position **8**

4.1 Requirements for the installation of the Torquemeter and the Slip ring 9

4.2 Design of the structure: Conceptual and embodiment design phase 11

4.2.1 First conceptual idea developed 11

4.2.2 Fixing points 12

4.2.3 Special parts designed for the fixing points 14

4.2.4 Fixing of the stator-ring 17

4.2.5 Development of the shape of the structure 18

4.2.6 Special part designed to fix the stator-ring 21

4.2.7 Special part designed to fix the DLM sensors 23

4.2.8 Fixing of the slip ring 25

4.2.9 Final assembly and detailed design 26

5 Design of the structure for the second position **28**

5.1 Design of the structure: Conceptual and embodiment design phase 28

5.1.1 First conceptual idea developed 28

5.1.2 Fixing points 29

5.1.3 Special parts designed for the fixing points 31

5.1.4 Development of the shape of the structure 32

5.1.5 Special part to fix the DLM sensors 33

5.1.6 Final assembly and detailed design 34

6 Design of the structure for the third Position **36**

6.1 Design of the structure: Conceptual and embodiment design phase 36

6.1.1 First conceptual idea developed 36

6.1.2 Fixing points 37

6.1.3 Development of the shape of the structure 38

6.1.4 Special part to fix the DLM sensors 39

6.1.5 Final assembly 40

7 Summary and conclusions **42**

References **V**

Appendix **VI**

List of Figures

2.1 Comparison between main shaft torque and rated torque. From *Reliability and Energy Yield Increase of Wind Turbines as a Benefit of Dynamic Load Reduction Operation.* . . . 3

2.2 Comparison of drive train damping strategies in time and frequency domain. From *Reliability and Energy Yield Increase of Wind Turbines as a Benefit of Dynamic Load Reduction Operation.* . . . 3

3.1 System structure of the Dynamic Load Monitor. From *Installation manual for Dynamic Load Monitor.* . . . 5

3.2 Sensor Control Unit. From *Installation manual for Dynamic Load Monitor.* . . . 6

3.3 Positioning of the DLM sensors along the turbine. . . . 6

3.4 Steel tension strip with encoder structure. From *Installation manual for Dynamic Load Monitor.* . . . 6

3.5 Sensor housing of one of the speed sensors. From *Installation manual for Dynamic Load Monitor.* . . . 7

4.1 First position for the installation of the sensors of the DLM system. . . . 8

4.2 Torquemeter. Rotor and Stator-ring. From *Manual F23iS Torquemeter.* . . . 8

4.3 Position of the rotor. . . . 9

4.4 Position of the slipring. . . . 9

4.5 Allignment between the stator and the rotor. From *Manual F23iS Torquemeter.* . . . 10

4.6 First evolved concept of the structure. . . . 11

4.7 First evolved concept of the structure attached to the generator. . . . 11

4.8 Rexroth aluminium strut profile: 45x45L. From *Rexroth Bosch Group web page.* . . . 12

4.9 First possible fixing point. . . . 12

4.10 Second possible fixing point. . . . 13

4.11 Possible metal sheet. . . . 13

4.12 Third possible fixing point. . . . 14

4.13 Fourth possible fixing point. . . . 14

4.14 Central bolt system. From *Rexroth Bosch Group web page* . . . 15

4.15 Central bolt classification. From *Hytecgroup web page.* . . . 15

4.16 Screw and nut, for which it is necessary to leave space. . . . 16

4.17 Metal sheet for the connection of each one of the profiles to the grey metal sheets. 16

4.18 Resistance material gained employing countersunk screws. . . . 17

4.19 Metal sheet for the connection of the profiles with the screws under the shaft. . . . 17

4.20 Holes in the stator ring. From *Manual F23iS Torquemeter.* . . . 17

4.21 Holes in the evaluation unit. From *Manual F23iS Torquemeter* . . . 18

4.22 Flexible structure developed. 18
4.23 Adjustment in the axial direction. 19
4.24 Adjustment in the vertical direction. 19
4.25 Adjustment in the horizontal direction. 20
4.26 Adjustment of the angle in the horizontal direction. 20
4.27 Adjustment of the angle in the vertical direction. 20
4.28 Rexroth 45x45 brackets. From *Rexroth Bosch Group web page* 21
4.29 Profiles with a special connection. 21
4.30 First possible option to fix the evaluation unit. 22
4.31 Second possible option to fix the evaluation units. 22
4.32 Holes inside the box to fix it to the evaluation unit. 22
4.33 DLM sensor and sensor housing. 23
4.34 Rexroth T-nuts. 24
4.35 Plate to fix the DLM sensors. 24
4.36 Hole in the slip ring. 25
4.37 Profiles that will hold a screw at the end of their length. 25
4.38 Ropes or strings system to keep the slip ring from rotating. 26
4.39 Final designed structure for the first position of the measurement systems. 26
4.40 Final designed structure for the first position of the measurement systems placed in the turbine. 27
4.41 Final result in reality. 27
5.1 Second position for the installation of the sensors of the DLM system. 28
5.2 First evolved concept for the structure. 29
5.3 First evolved concept for the structure. 29
5.4 Blue triangular parts at both sides of the gearbox. 30
5.5 Series of screws around the generator case. 30
5.6 Screws used for fixing the structure. 31
5.7 Metal sheet for the connection of the profiles. 32
5.8 Designed structure to fix the sensors in their exact position. 32
5.9 Designed structure to fix the sensors in their exact position assembled with the gearbox. 33
5.10 Hole-slot system. 34
5.11 Plate for designed to fix the DLM sensors. 34
5.12 Final designed structure. 35
5.13 Final designed structure in the whole turbine. 35
6.1 Third position for the installation of the sensors of the DLM system. 36
6.2 Component from which to fix the structure. 37
6.3 Straight part of the first nerve 37
6.4 Arm not rigidly enough fixed on the second nerve of the component. 38
6.5 Drilled holes on the nerves. 38

6.6 Defined position of the sensors. 39
6.7 Developed arm for the third measurement position 39
6.8 Metal tubes to guide the screws. 39
6.9 Metal sheet for fixing the sensors 40
6.10 Final designed structure. 40
6.11 Final designed structure placed in the turbine. 41

Nomenclature

Indices

Index	Description
CM	Condition Monitoring
DLM	Dynamic Load Monitor
ATC	Active Torque Control
SCU	Sensor Control Unit

1 Introduction

Maintenance of wind power, especially offshore, is known to be difficult and expensive. The reasons behind this problem are related to unexpected failures, spare parts and equipment availability, and weather conditions. This leads to increases in operation and maintenance costs and long down times, rising the cost of energy. In order to make maintenance more efficient, Condition Monitoring Systems (CMS) provide solutions to this problem. Instead of having fixed intervals for maintenance to prevent the components from failure as corrective and preventive maintenance do, condition monitoring maintenance bases the schedule of the maintenance activities and the condition of machinery on real data obtained while operating. Condition monitoring not only helps to reduce the possibility of catastrophic failure, but also allows to order parts in advance, schedule manpower, and plan other repairs during the downtime.

The condition monitoring system is being implemented in the research turbine of the institute to analyse the different machinery conditions when the generation of overloads and damages on the components of the turbine, in order to instore new conditions and design changes on the components that will avoid this overloads.

This thesis is focused on the installation of the Dynamic Load Monitor (DLM) system, which is a condition monitoring system that consists on a contact-free speed and torque measurement system based on standard automotive sensors that provide the dynamic load data for wind turbine optimization.

The dynamic load monitor consists of a Sensor Control Unit, which will be mounted in the nacelle, and three measurement positions, each of them consisting of one steel tension strip mounted like a waist belt on the shaft and two sensors. The installation of the sensors of the Dynamic Load Monitor system has to fulfill a serie of requirements so that the sensors obtain an addecuate signal for the measurements.

For placing the sensors at their exact position a series of structures have to be developed and built, and this is the main aim of this thesis.

For the design process of this structures the systematic approach defined by Pahl/Beitz will be followed:

- First a clarification and specification of the task will be made by defining the requirements that have to be fulfilled for the installation of the sensors.

- Secondly, the conceptual design phase starts. All the possible mechanisms that fulfill the requirements have to be considered and evaluated.

- Then the embodiment design phase takes place. A selection of the appropriate structure has to be made and all the appropiate parts have to be designed.

- Finally a detailed design of the defined structures is carried out, the technical drawings have to be made and incorporated in the whole assembly model of the turbine.

2 Condition Monitoring for Wind Turbine Optimization: Dynamic Load Monitor (DLM)

Condition monitoring (CM) is defined as the process of monitoring a parameter of condition in machinery such that a significant change is indicative for a developing failure.

Today most of the maintenance actions are carried out either by a preventive maintenance or a corrective maintenance approach. Preventive maintenance generally has fixed intervals to prevent the components from failure whereas corrective maintenance is only performed after a fault or breakdown has occurred. These approaches prove very costly in many cases due to losses in production, the cost of keeping spare parts, quality deficiencies etc.

Condition based maintenance, or condition monitoring, involves the measurement or monitoring of specific parameters which directly correspond to a machine. The main difference between preventive maintenance and condition based maintenance is that condition based maintenance uses various methods of monitoring for checking the condition of the machine to determine the actual mean time for failure, whereas preventive maintenance depends upon industrial average life statistics. This is explained in [Sharma u. Mahto, 2013].

The objectives of Condition Monitoring, as defined in [Sheng u. Veers, 2011], are the following:

- Detecting incipient failures early, thereby reducing the chances of catastrophic failures;
- Accurately evaluating component health conditions, which has the potential to enable more cost-effective Operation and Management;
- Analyzing root causes, which may provide the inputs for improved machine operation, control strategy, and component design.

2.1 DLM system applied to wind turbines

Wind shear and turbulence as well as resonant vibrations generate high dynamic loads on the components of a wind turbine.

The non-contact and thus wear-free load measurement of the DLM system in the drive train allows to avoid overloads and damages before they affect the lifetime of the major components. This brings down service costs and ensures higher energy yields.

The DLM system measures the rotation speeds and torques in the drive train and evaluates them with respect to stationary, dynamic and special load events. Torque and speed overloads as well as critical operation conditions in the drive train become instantly recognizable (see figure 2.1).

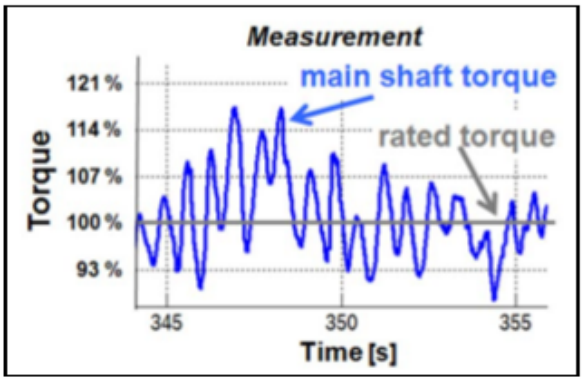


Figure 2.1: Comparison between main shaft torque and rated torque. From *Reliability and Energy Yield Increase of Wind Turbines as a Benefit of Dynamic Load Reduction Operation.*

This way, after running tests in a research wind turbine it is possible to adjust the conditions or the design of some of the components in order to avoid overloads.

By comparing the actual loads with the design loads of the major components, operators and manufacturers obtain important information to estimate the residual life of these components and, where appropriate, to achieve run-time extensions.

In addition, the results of the measurements of DLM offer manufacturers and operators the ability to dynamically adjust the performance curve of the turbine to the different operating conditions. Thus not only are overload and damage reduced, but the energy yield of the turbine can also be increased. This is illustrated in [Vath, 2013].

2.2 Active Torque Control (ATC)

The real time measurement data provided by the DLM can be used for Active Torque Control to reduce the torque and speed oscillations by actively adjusting the generator torque to the incoming wind loads.

A comparison between the different drive train damping strategies is shown in figure 2.2. In Figure 2.2 the drive train torque shows significant reduction of torque oscillations with the state-of-the-art damping in the frequency range between 1.5 Hz and 2.2 Hz. Besides this reduction of the oscillations for the first torsional eigenfrequency, in most turbines there is an increase of torque oscillations outside this frequency range.

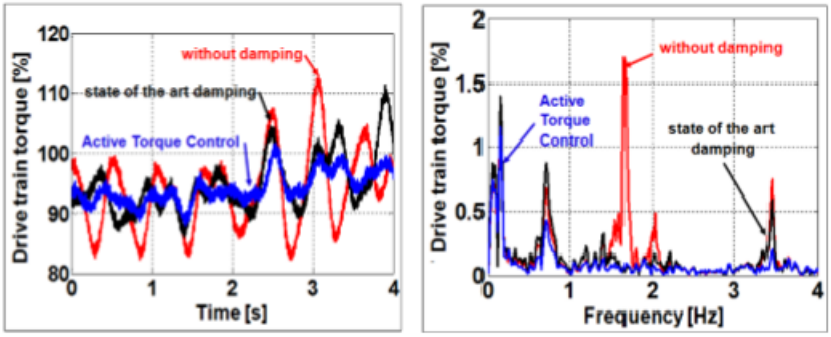


Figure 2.2: Comparison of drive train damping strategies in time and frequency domain. From *Reliability and Energy Yield Increase of Wind Turbines as a Benefit of Dynamic Load Reduction Operation.*

When using Active Torque Control based on the real drive train torque and speed measurement, there is a better damping of the first torsional eigenfrequency than with a conventional design using a band-pass filter. Furthermore ATC works in a wide frequency range, from about 0.1 to 10 Hz. This is why ATC is also able to dampen the oscillations of the drive train in combination with blade oscillations at about 3.5 Hz and oscillations caused by wind speed fluctuations at about 0.1 to 0.2 Hz. In addition to that, the speed-variable frequencies at about 0.7 Hz can also be reduced significantly.

Theoretically, more than 80% of the damaging loads, relating to hertzian pressure inside the gearbox, are resulting from a torque loading of more than 95% of the nominal torque. Therefore torque oscillations result in high damaging loads, which could be avoided by using Active Torque Control. With ATC the dynamic torque oscillations can be reduced to a minimum, which results in less loads for all torque-stressed components. The comparison in the measurement for a wind turbine shows a reduction of the damaging loads for the gearbox with Active Torque Control, which can be used for an increase in energy yield. Furthermore this reduction of dynamics ensures a higher reliability of the drive train components. This is explained in [Vath, 2013].

3 Clarification of the task: installation and definition of requirements

3.1 Requirements for the installation

There are a series of conditions which have to be fulfilled when the installation of the DLM is prepared in order to have a successful performance of the system.

The dynamic load monitor consists of a Sensor Control Unit (SCU) and three measurement systems placed at the main shaft.

As illustrated in Figure 3.1, the Dynamic Load Monitor consists of two sensor units, which are installed at the main shaft to measure the speed and torque of the main shaft. There is another sensor unit installed at the high speed shaft to measure the speed of the high speed shaft and, in combination with the sensor units of the main shaft, also the gearbox torque.

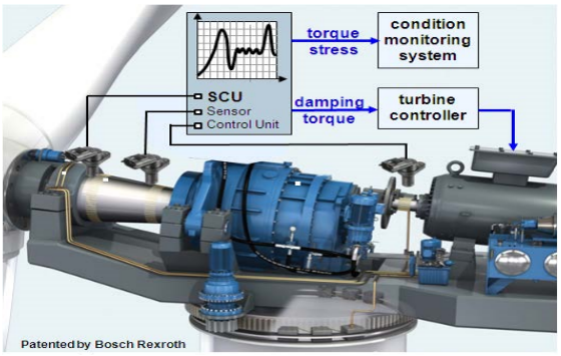


Figure 3.1: System structure of the Dynamic Load Monitor. From *Installation manual for Dynamic Load Monitor.*

The sensor units measure the speed using steel strips with an encoder structure or an existing encoder structure inside the wind turbine drive train. These sensors are connected to the Sensor Control Unit (SCU) which provides a direct mean to measure and further evaluate the torque flux transmitted through the turbine drive train. The measurements are derived from the torsion of the original drive train components observed as differential angle variations over defined components sections. Furthermore the temperature of the gearbox and the pressure of the gearbox oil supply could be monitored with the DLM technology.

The Sensor Control Unit will be mounted in the nacelle, where the vibrations are quite low and the temperature is less than 40^{o}C. The SCU itself has a vibration damper between the mounting plate and the housing of the sensor control unit. The SCU is shown in figure 3.2.

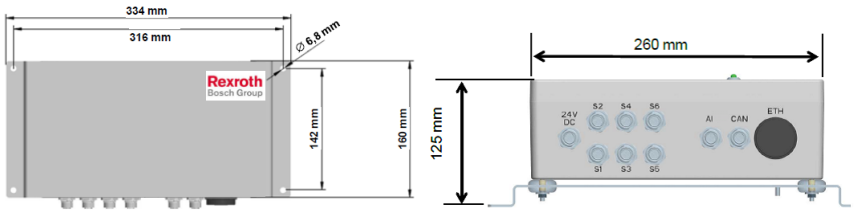


Figure 3.2: Sensor Control Unit. From *Installation manual for Dynamic Load Monitor.*

As it was just mentioned, there are three different poisitions for measurement. Two of this positions have to be located in the mainshaft, as far from each other as possible so the displacement angle can be measured with accuracy.

The third measurement system has to be located between the gearbox and the generator, as close to one of them as possible so that the structure designed to hold the system is shorter.The distribution of the different positions is shown in figure 3.3.

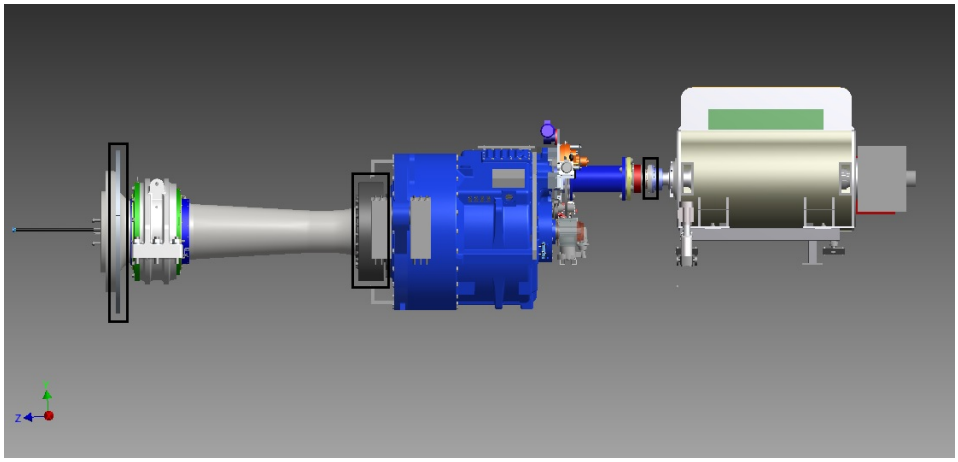


Figure 3.3: Positioning of the DLM sensors along the turbine.

Each of the measurement positions consists of one steel tension strip and two sensors.

The steel tension strips with encoder structure (Figure 3.4) are tightened like a waist belt at the defined positions on the main shaft. The strip lock is welded securely to the strip for maximum tension force, holding the strip securely on the shaft. The torque for the bolt should be tightened with a torque wrench and a value of 5 Nm. The distance between the steel strip and the shaft has to be less than 0.2 mm at any position.

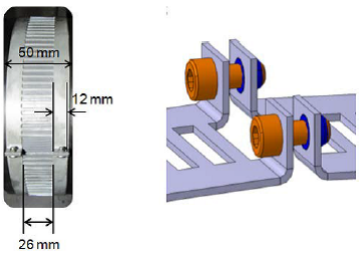


Figure 3.4: Steel tension strip with encoder structure. From *Installation manual for Dynamic Load Monitor.*

The sensors are mounted in a special sensor housing (Figure 3.5) to protect them from damage, especially during service and maintenance activities. The connection of the sensors to the SCU is donde by a plug connector at the sensor housing.

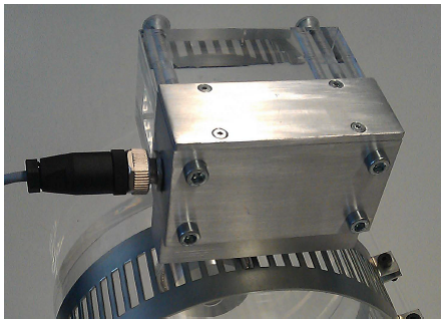


Figure 3.5: Sensor housing of one of the speed sensors. From *Installation manual for Dynamic Load Monitor.*

The sensor housing has to be mounted exactly in the middle between the strip locks of the steel strip to secure sufficient service conditions, also when the shaft is moving in axial direction.

Once the first sensor is placed, the second one has to be installed at the opposite position of the shaft, which means at an angle between 170^{o} and 190^{o} degrees.

The mounting of the sensor is a very important point to achieve a sufficient signal quality. The distance between the sensor and the steel strip with the encoder structure has to be between 1.2 mm and 1.4 mm. For the radial and lateral alignment and angle between 89^{o} and 91^{o} degrees is necessary. Furthermore the rotational direction of the shaft is the direction of the cable connection.

A requirement list following the procedure of *Pahl/Beitz* is created, clearly elaborating the goals and the circumstances under which they have to be performed. The resulting requirements must be identified either as demands (the requirements that must be met under all circumstances) or wishes (the requirements that should be taken into consideration whenever possible):

Demands

- The two sensors (in each measurement position) need to be positioned on each side of the shaft, forming an angle between 170^{o} and 190^{o}.

- The distance between the sensor and the steel strip has to be between 1.2 mm and 1.4 mm.

- For the radial and lateral alignment an angle between 89^{o} and 91^{o} is required.

Wishes

- Provide the possibility to adjust the position of the sensor in the radial direction.

- The structure should be as stiff as possible.

- The simpler the structure is, the smaller the probability of any kind of failure.

4 Design of the structure for the first position

For the first position it is needed that the sensor system is placed between the gearbox and the generator, as close to one of them as possible so that the structure designed to hold the system is shorter, in this case is placed close to the generator. It is also required to find an appropiate geometry for the installation.

The chosen position is shown in figure 4.1.

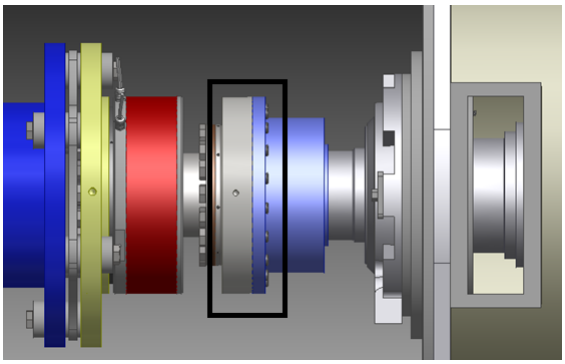


Figure 4.1: First position for the installation of the sensors of the DLM system.

Because of the location, the structure will also be used to install a Torquemeter and a Slip ring.

The torque measurement system is composed of the rotor, which is already installed in the whole of the turbine, and the stator-ring (that in this case also incorporates the evaluation unit). See below figure 4.2.

Figure 4.2: Torquemeter. Rotor and Stator-ring. From *Manual F23iS Torquemeter.*

The stator-ring will be placed around the rotor. The position of the rotor is shown in figure 4.3.

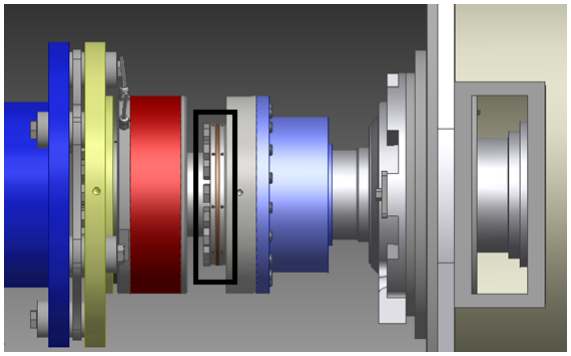


Figure 4.3: Position of the rotor.

The slip ring is the part coloured in red and grey in figure 4.4.

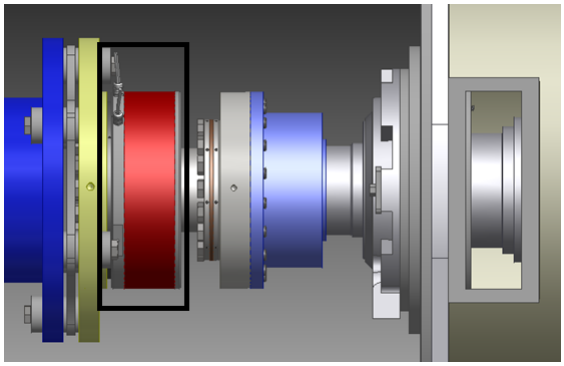


Figure 4.4: Position of the slipring.

The requirements for the installation of the torquemeter and the slip ring need to be defined and a new requirements list needs to be created.

4.1 Requirements for the installation of the Torquemeter and the Slip ring

Torquemeter

It is needed to install the stator-ring in such a way that the allignment between the stator and rotor fulfills the requirements.

The axial displacement between rotor an stator should be 1 mm ± 1 mm, and the nominal radial airgap between rotor and stator is 3mm with and allowed excentricity of ± 2 mm. See figure 4.5.

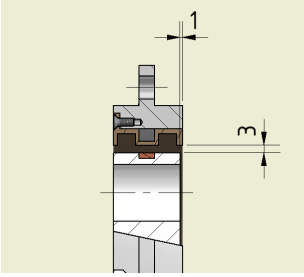


Figure 4.5: Allignment between the stator and the rotor. From *Manual F23iS Torquemeter.*

The requirements list is created according to the procedure of *Pahl/Beitz*:

Demands

- The axial displacement between rotor an stator has to be 1 mm ± 1 mm.
- The nominal radial airgap between rotor and stator is 3 mm. Allowed excentricity is ± 2 mm.
- Under no circumstances should the stator touch the rotor.
- We have to provide the possibility to adjust the stator-ring at its exact position.

Wishes

- The structure should be as rigid as possible.

Slip ring

The rotation of the slip ring has to be avoided.

Demands

- Two fixed points to anchor the slip ring.
- It is important to make sure that the radial wires that come out of the slip ring do not get in touch with any rotating part.

4.2 Design of the structure: Conceptual and embodiment design phase

The structure has to fulfill all the requirements defined for the DLM sensors, for the torquemeter and for the slip ring.

4.2.1 First conceptual idea developed

First, a basic idea on how the structure will look like is developed. This first concept is evolved from two principles:

- The structure will be fixed to the case of the generator.

- The essential aim of the structure it is to reach the position of installation of the sensors, the rotor and the slip ring.

Following this criteria, a general idea for the structure is formed as shown in figure 4.6.

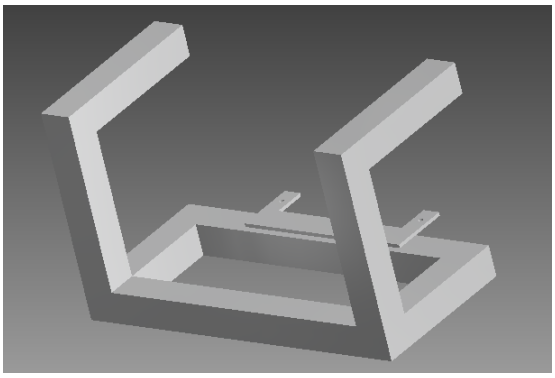


Figure 4.6: First evolved concept of the structure.

When attached to the generator case it will look like the following figure 4.7.

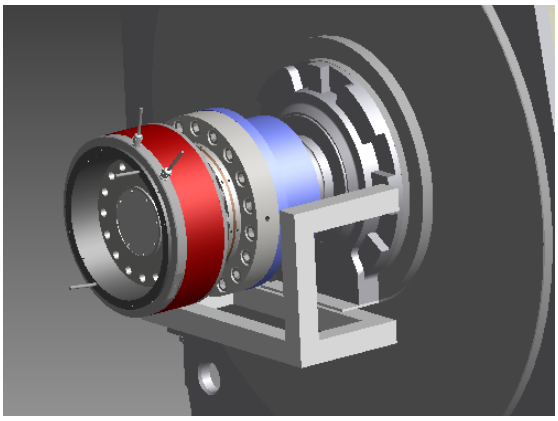


Figure 4.7: First evolved concept of the structure attached to the generator.

The structure will be built from a series of profiles connected in different points to the case of the generator.

The structure has to be as light as possible, so that the fixing points do not have to support a very high load from the profiles, but at the same time it has to be rigid. That is why the Rexroth

aluminium strut profiles are chosen to be the profiles of the structure. They are light and stiff and they offer a very large modular profile system for a wide variety of applications. They also have many other advantages, as a shorter assembly time, need of fewer tools, smaller production areas, reusable components, corrosion resistance and flexible expansion and conversion.

There are several sizes and shapes offered by Rexroth, the basic 45x45L (Figure 4.8) shape is the one chosen for the structure. It enables assembly in the four faces of the profile and has an appropiate size for our construction.

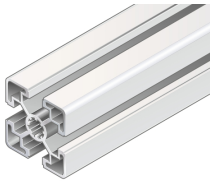


Figure 4.8: Rexroth aluminium strut profile: 45x45L. From *Rexroth Bosch Group web page.*

4.2.2 Fixing points

After having developed a brief idea of the structure and having determined the profiles that are going to be used, the most important part is to define how the construction will be fixed to the case of the generator.

Having had a closer look at the location of the structure it is possible to determine four different alternatives for the attachment. This options are considered and evaluated ahead:

- There are two grey metal sheets placed at both sides of the shaft. In each of these sheets there are 4 threatened holes. It is possible to make use of those holes to attach the structure, and this way, the grey metal sheets could become two fixing points.

The metal sheets are symmetrically situated 180^{o} degrees far from each other, with the 4 holes arranged as it is possible to see in figure 4.9.

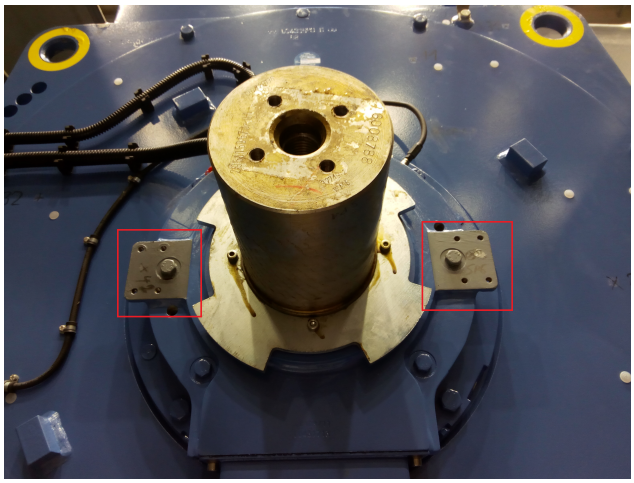


Figure 4.9: First possible fixing point.

It could be possible to fix a metal plate to each one of the grey metal sheets by making use of the four holes, and then fix a profile from the metal plate. As the grey metal sheets are situated 180^{o} from each other, the profiles fix from them represent an adeccuate place where to posistion

the DLM sensors, fulfilling the requirement of poisitioning the sensors at an angle between 170^{o} and 190^{o} from each other.

- There are two screws situated under the shaft, that are fixing a box for possible oil spills from the generator. See below figure 4.10.

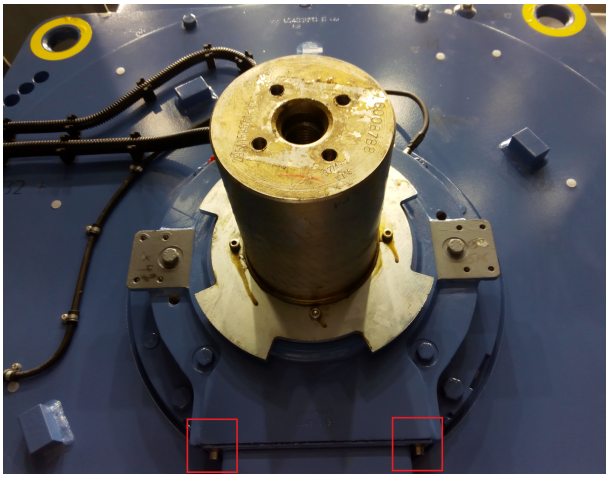


Figure 4.10: Second possible fixing point.

It could be possible to use those screws to insert a metal plate that would become another fixing point for the structure. The metal sheet will look like the following one in figure 4.11, not to interfere with the oil flow.

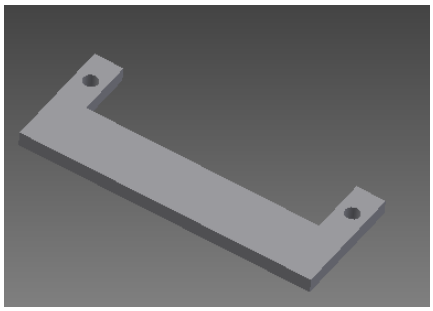


Figure 4.11: Possible metal sheet.

A profile could be attached to the metal sheet and this way it would become another fixing point for the structure.

Analyzing this option more carefully, it is found out that there is a plastic layer between the the box for oil peaks and the generator. This will mean that this plastic layer will be located between the generator and the metal plate and that the fastening of the screws will lead to a comprension of the plastic material, making this fixing point not appropiate for the structure.

- There are also four metal blocks that are welded to the generator case where it could be possible to drill a hole. This way they could be used as another four fixing points. The asymmetrical disposition of those blocks is what makes them a complex and not adeccuate fixing point. They are shown in picture 4.12.

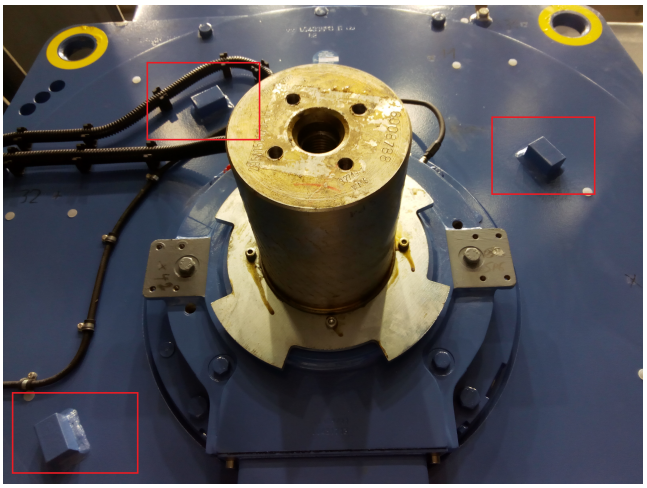


Figure 4.12: Third possible fixing point.

- The last of the possible fixing points are a series of M16 screws that are attaching the case of the generator to the generator. It is checked that the loosening of these screws is possible without affecting the functionality of the generator. A metal plate could be inserted between two of the screws and the case, and the actual screws will be replaced for longer ones. Then, the profiles could be fix from the metal sheet. Just by loosening the two screws which are situated under the shaft, it could be possible to create two new fixing points. See below figure 4.13.

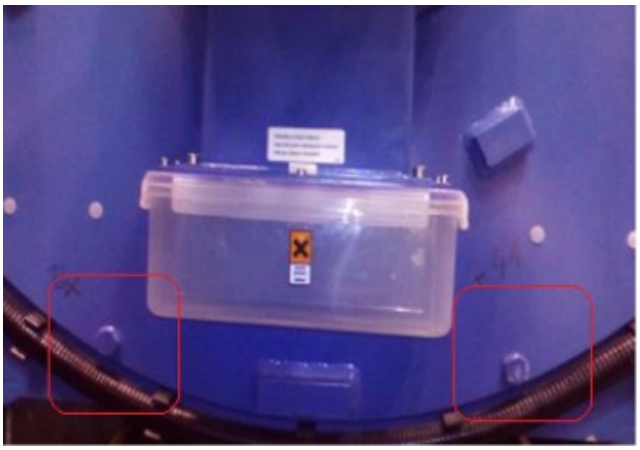


Figure 4.13: Fourth possible fixing point.

After an evaluation of all the possibilities, it is decided that the most appropiate fixing points are the first and last option, that are, the grey metal sheets situated at both sides of the shaft and the screws that are attaching the case of the generator to the generator.

4.2.3 Special parts designed for the fixing points

With the two fixing points of the grey metal sheets the structure will count with two fixing positions situated 180^{o} degrees from each other in the horizontal edge. Combining them with the two fixing points from the screws situated under the shaft the structure will be properly fixed.

Once the fixing points are chosen it is needed to develop the specific design on how the structure will be fixed to them.

- For the two fixing points of the grey metal sheets it is needed to design two identic metal plates that will be fixed to them. The metal plates will be two 10 mm thick steel plates with four holes arranged in the same position as the ones in the grey metal sheets in order to fasten them, and another hole to fix the profiles.

The holes on the grey metal sheets of the generator case are M8, so the designed metal plate will count with four 9 mm diameter holes. A H13 adjustment has been chosen to take into account possible deviations from the taken measurements. To fasten the plates, eight M8x1.25 allen screws (DIN EN ISO 4017) with 16 mm length are used.

To fix the profile to the metal sheet a central bolt is used. The system works as shown in figure 4.14.

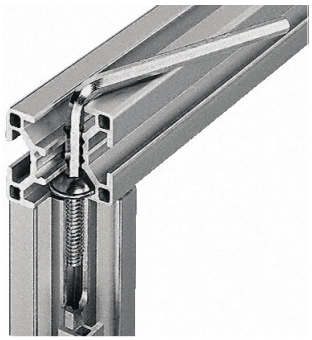


Figure 4.14: Central bolt system. From *Rexroth Bosch Group web page*

The central bolt will be introduced in the middle of the profile, that has to be previously threatened. And the metal sheet will be located between the profile and the bolt.

Instead of a S12 screw, which is the one used when attaching two profiles, a M12 screw will be used as the load they can support is higher. This is shown in figure 4.15.

Size	F_{max}	M_{max}
S6	500 N	8 Nm
S8	800 N	43 Nm
S12	1300 N[1)]	80 Nm
M12	3000 N[2)]	80 Nm

[1)] Only applies for S12
[2)] Only applies for M12

Figure 4.15: Central bolt classification. From *Hytecgroup web page.*

This way two M12x1.75 cylindrical screws with hexagon socket (as there is not much space to fasten them)(DIN 7984) and 40mm length will be used.

A 13 mm diameter through hole will be drilled in the metal sheet for the M12 screws. A H12 adjustment will be used as the profiles are being positioned. The hole in the centre of the profile will also have to be drilled with a M12.

When designing the plate it is needed to take into account one last detail. As it is possible to see in the following figure 4.16, there is a screw with a nut between two of the holes, so it is important that the plate leaves space for this nut.

Figure 4.16: Screw and nut, for which it is necessary to leave space.

Finally the metal sheet will look like the one in figure 4.17.

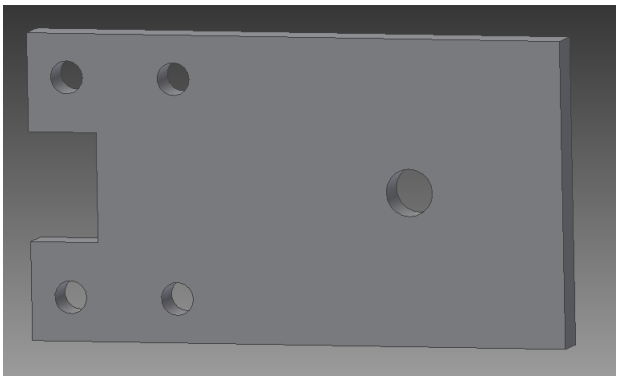


Figure 4.17: Metal sheet for the connection of each one of the profiles to the grey metal sheets.

- Two profiles will be attached from the fixing points of the screws under the shaft. As it was explained before a metal plate has to be designed to attach those profiles to the generator case. As the metal plate will be fixed to the generator case by two screws, a single plate has to be developed in order to avoid the tilting movement that could occur if there were two plates only attached by one screw each.

To fix the plate to the generator case two of the M16 screws are used. This way two through holes of 17.5 mm diameter will be drilled in the plate. A H13 adjustment has been chosen in order to avoid possible deviations in the measurements. Then the two M16 screws will be replaced for other same M16 screws but 10 mm longer to cover the thickness of the metal sheet.

For fixing the profiles to the metal sheet the same kind of system with central bolts as in the two previous fixing points will be used. The only difference is that in this case there is no space between the metal sheet and the generator case, so the heads of the screws have to go inside the metal sheet. For this reason two M12x1.75 countersunk screws with hexagon socket (DIN EN ISO 10642) with a lenght of 40 mm will be used. With this kind of screws instead of normal cylindrical screws more effective resistance material is left between the screw and the metal sheet, so the union is stiffer.

With the countersunk screw it is possible to gain al the material highlighted in red in figure 4.18.

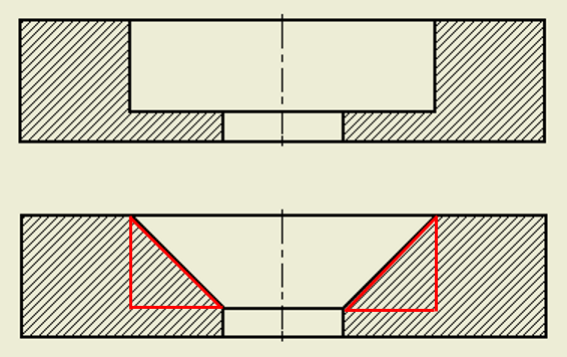


Figure 4.18: Resistance material gained employing countersunk screws.

The metal sheet will be designed following the contour of the case. It is also needed to leave some space in the central part of the metal sheet for a metal block placed in the generator case.

Finally the metal sheet will look like the figure 4.19.

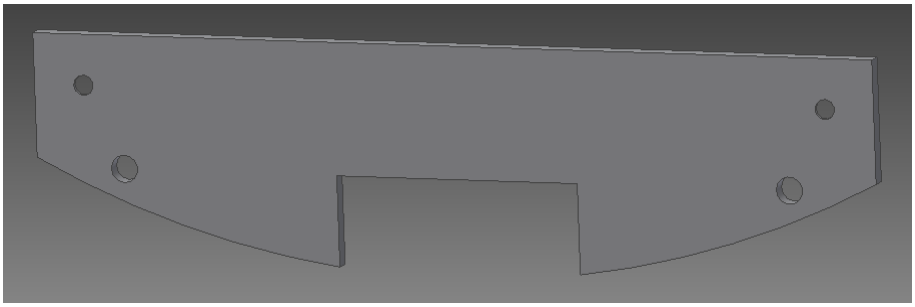


Figure 4.19: Metal sheet for the connection of the profiles with the screws under the shaft.

4.2.4 Fixing of the stator-ring

Once the fixing points are chosen and defined it is time to design the rest of the structure.

One of the most crucial points is the placement of the stator-ring. There are two different possibilities to fix the stator:

-The stator-ring is provided with a series of holes around the ring itself to fix it. See below figure 4.20.

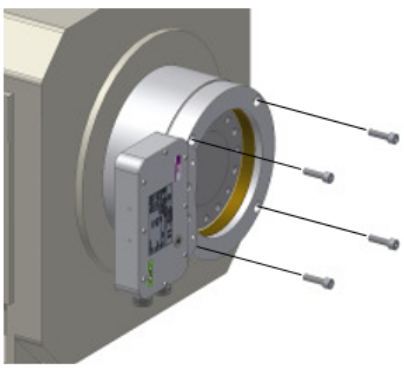


Figure 4.20: Holes in the stator ring. From *Manual F23iS Torquemeter.*

-The evaluation unit which is attached to the stator-ring has 4 holes in the bottom that can also be used to fix it. See below figure 4.21.

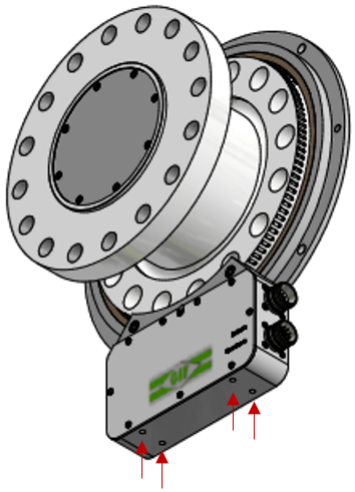


Figure 4.21: Holes in the evaluation unit. From *Manual F23iS Torquemeter*

Evaluating this two options, it is chosen to fix the stator by the holes in the evaluation unit. This is due to the fact that all the structures around the rotor are rotating, and it is not possible to fix in them the stator-ring from the holes in it. This way, it is much simpler to fix the stator-ring from the evaluation unit.

4.2.5 Development of the shape of the structure

The shape of the structure is deduced from this decision. It is needed to reach the position of the rotor under the shaft, to fix there the evaluation unit so that the stator-ring is located in its exact position. As it was mentioned before the two profiles fixed to the grey metal sheets on both sides of the shaft will be used to fix the sensors.

It is important now to take into account all the requirements defined before according to the procedure of *Pahl/Beitz*. It is needed that the position of the stator-ring is flexible and adjustable. Following this demand a flexible construction is developed, as shown in figure 4.22.

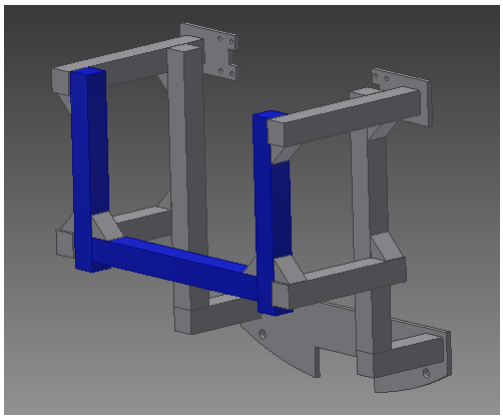


Figure 4.22: Flexible structure developed.

The main feature of the structure is the assembly coloured in blue, formed by three profiles that together make a U-shape. The evaluation unit will be fixed on the profile at the bottom. With this U-shaped structure it is possible to gain all the degrees of freedom necessary for the positioning of the stator-ring:

- Possible displacements and adjustments in the axial direction, by moving the vertical profiles in the axial direction. See below figure 4.23.

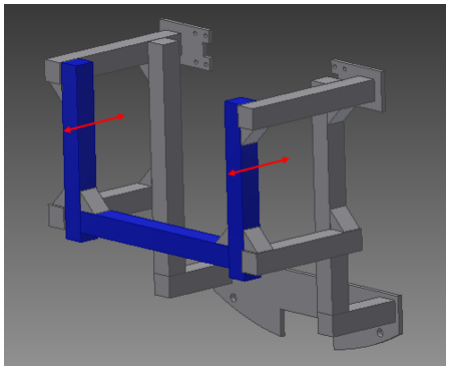


Figure 4.23: Adjustment in the axial direction.

A calculation of the possible necessary adjustments has been made to determine the required extra length for the profiles in axial direction. As some of the measuremets of the generator case have been made manually, there can ben an error of maximum ± 2 mm and adding the possible excentricity allowed by the position of the stator-ring of ± 1 mm in axial direction, the total is ± 3 mm. A safety net is added and finally the sum is ± 5 mm.

- Possible displacements and adjustments in the vertical direction, by moving the horizontal profile in the vertical direction. See below figure 4.24.

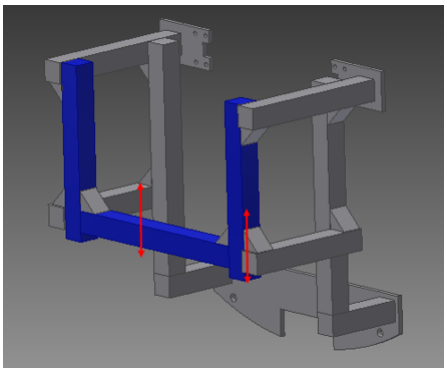


Figure 4.24: Adjustment in the vertical direction.

The same calculation as before is carried out, and again a ± 5 mm extra length for the vertical profiles is needed.

- Possible displacements and adjustments in the horizontal direction, by moving and adjusting the evaluation unit along the lower horizontal profile of the U-shape. See below figure 4.25.

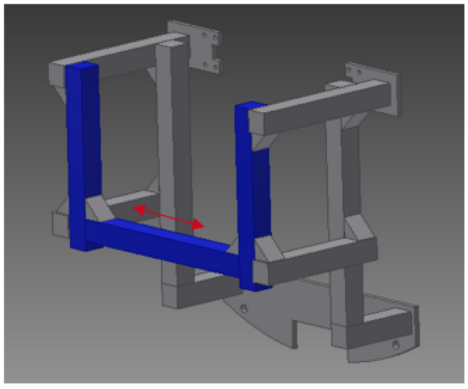


Figure 4.25: Adjustment in the horizontal direction.

-Possible adjusments of the angle in the horizontal direction, by tilting the vertical profiles. See below figure 4.26.

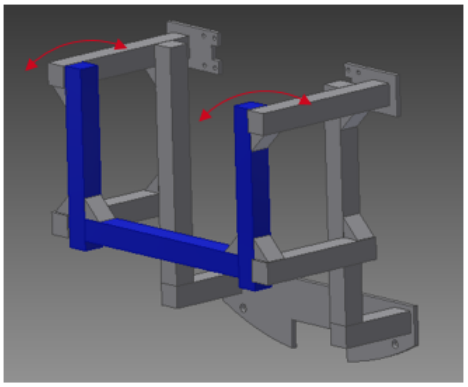


Figure 4.26: Adjustment of the angle in the horizontal direction.

-Possible adjustments of the angle in the vertical direction, by tilting one of the vertical profiles. This adjustment is only possible in a small range in order not to lose contact between the surfaces of the profiles. See below figure 4.27.

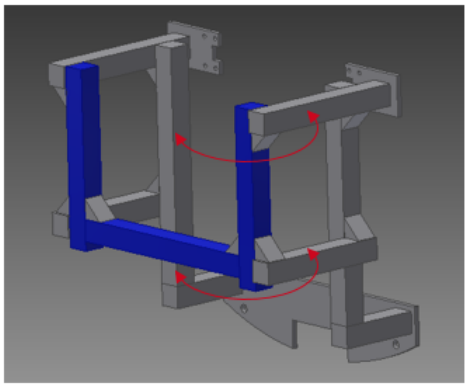


Figure 4.27: Adjustment of the angle in the vertical direction.

To make all this adjustments possible, the connection between the profiles will be done using the rexroth brackets (figure 4.28). For each of the brackets two M8x1.25 T- bolts and two M8 flange nuts are needed.

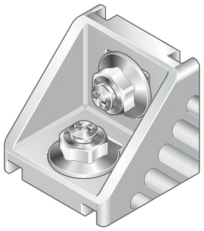


Figure 4.28: Rexroth 45x45 brackets. From *Rexroth Bosch Group web page*

There is only one exception, which is the connection between the horizontal profiles that are attached to the plate under the shaft and the vertical profiles connected to them. These are the profiles coloured in red in the following figure 4.29.

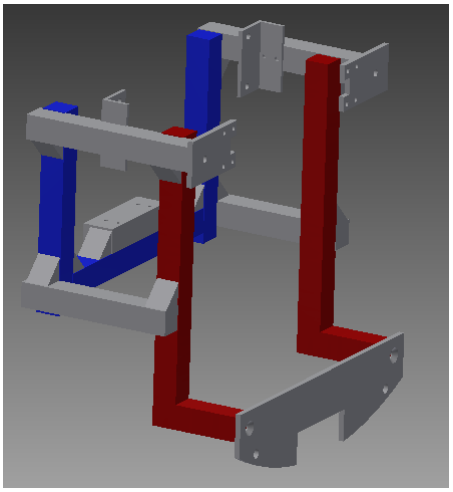


Figure 4.29: Profiles with a special connection.

As there is no need for this connection to be adjustable, this two profiles will be connected by a special rexroth central bolt, due to the fact that this type of connection is stiffer than the brackets. For this purpose, the center of the vertical profile will need to be threatened with an appropiate M12 threat a distance of 30 mm, and in the horizontal profile a 9.8 mm diameter hole will need to be drilled for access to the fastening tool.

4.2.6 Special part designed to fix the stator-ring

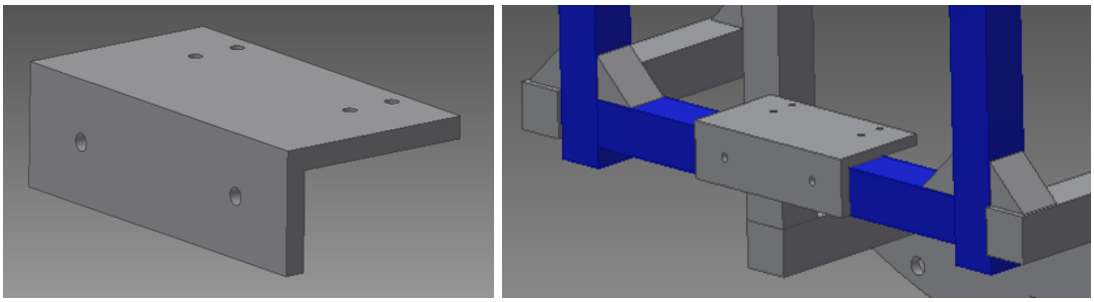
Now that the requirement for a flexible structure is achieved, it is needed to design how the evaluation unit is going to be fixed to the construction.

As it was described before, the four M6 holes on the bottom of the evaluation unit are going to be used to fix the stator.

This way, the evaluation unit has to be fixed to some kind of metal part which has to be fixed to the profile.

There are two different possibilities that have to be considered:

- A 10 mm thick metal L-shaped sheet, represented in figure 4.30, that matches with the square shape of the profile and is fixed to it in the front with two screws.

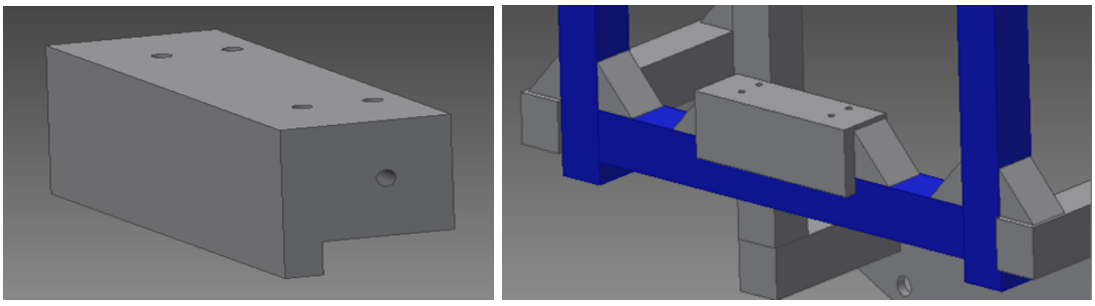


(a) Designed metal sheet. (b) Metal sheet fixed to the profile.

Figure 4.30: First possible option to fix the evaluation unit.

But this possibility does not assure the contact between the surface of the profile and the surface of the part.

- A similar idea but using a rectangular metal box instead of a metal sheet, as shown in figure 4.31. It will be attached to the profile with two brackets placed on both sides and to the evaluation unit from the inside.



(a) Designed metal box. (b) Metal box fixed on the profile.

Figure 4.31: Second possible option to fix the evaluation units.

The second option represents a much rigid choice, and it is the one chosen.

The box goes 10 mm longer on the front side to secure the fixing and the position. The box is fixed to the profile by two brackets, so it is needed to drill two M8 holes with 20 mm length on both sides of the box. As it was said before, the fixing of the box to the evaluation unit is done from the inside of the box. This means that the screws will be placed inside the box upside down, and that the heads of the screws are also placed inside the box. For this purpose four through holes of two different diameters have to be drilled from the bottom of the box. This is shown in figure 4.32.

Figure 4.32: Holes inside the box to fix it to the evaluation unit.

Four M6x1 cylindrical screws with hexagon socket (DIN 7984) and 45 mm length will be used to fix the box to the evaluation unit. This way the diameter of the holes inside the box have to be 6.6 mm for the small hole and 11 mm for the big hole, suited for the head of the screw. An H13 adjustment is used because the position of the holes in the evaluation unit was measured manually and there can be some error.

4.2.7 Special part designed to fix the DLM sensors

Once the fixing of the stator-ring is defined, the next step is the fixing of the DLM sensors.

The sensors are going to be fixed from the two horizontal profiles that go in the axis direction and are placed 180^{o} from each other.

To fix the DLM sensors, the sensor housing is provided with two through holes along the face of the housing, as it is possible to see in figure 4.33.

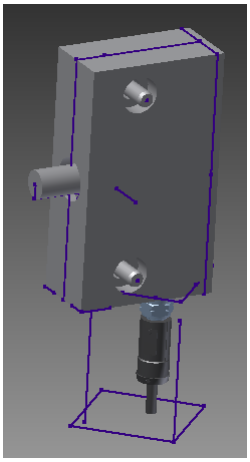


Figure 4.33: DLM sensor and sensor housing.

As it is seen in figure 4.33 the holes are placed perpendicular to the direction of the sensor, so it is not possible to fix the sensor housing in the axial direction but rather in the radial direction. This way a L-shaped sheet metal has to be designed. The biggest question is how to fix it to the face of the profile. There are different options for that purpose:

- It can be fixed to the profile with a bracket in the same way as the box for the stator-ring, but thus the union will only count with a single fixing point and will not be rigid enough.

- Another option is using a normal screw and the rexroth T-nuts. This system works as figure 4.34 describes.

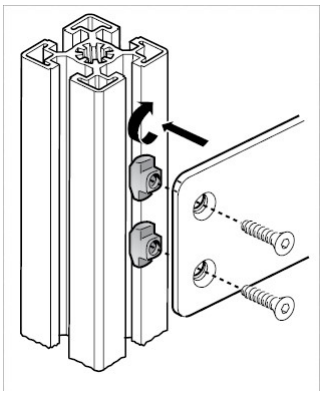


Figure 4.34: Rexroth T-nuts.

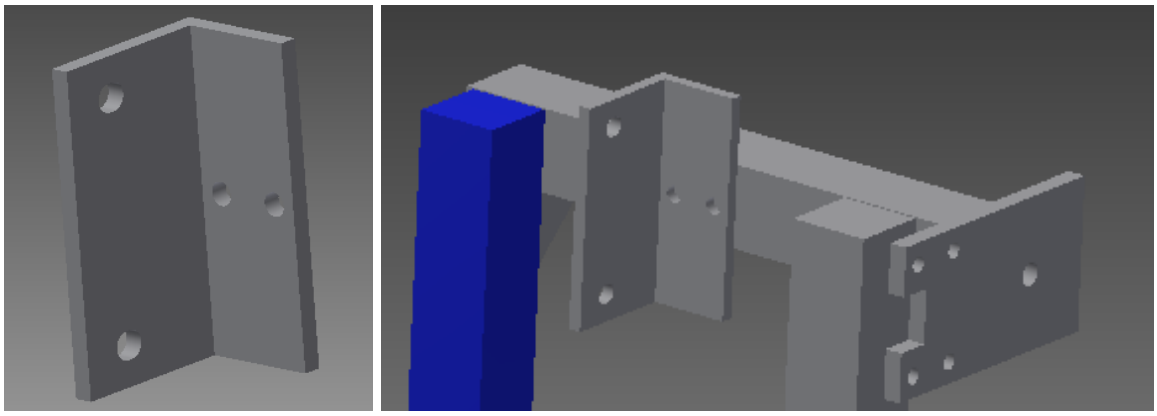
Two screws will be placed in order to have a enough rigid union.

This second option is the chosen one by following the criteria of the rigidest one.

The plate will be a 10 mm thick L-shaped metal sheet. To fix the sensor housing to the plate two M10x1.5 cylindrical screws with hexagon socket (DIN 7984) and 50 mm length will be used. In order to allow for possible adjustments in the radial direction, two slots of ± 1 mm and 10.5 mm diameter will be drilled in the plate arranged in the same disposition as the holes in the sensor housing. An H12 adjustment has been chosen, as the holes are used for positioning.

For the fixing to the profile, two screws and two nuts will be used as described before. As the profiles are 45x45 the respective t-nuts have a 10 mm groove with M8 holes. Two M8x1.25 cylindrical screws with hexagon socket (DIN EN ISO 4762) and 12 mm length and two M8 stainless steel T-nuts will be used. In the metal plate two through holes with 9 mm diameter will be drilled, separated 25 mm from each other, as there has to be at least the length of the T-nuts, 20 mm, between each other.

This way the plate will look like the one in figure 4.35.



(a) Designed metal plate. (b) Location of the metal plate.

Figure 4.35: Plate to fix the DLM sensors.

4.2.8 Fixing of the slip ring

The last component that has to be taken into account is the slip ring.

The requirement for the slip ring is that it has to be prevented from rotating. It is important to note that the slip ring counts with a single 5 mm diameter hole, as it is seen in the figure 4.36.

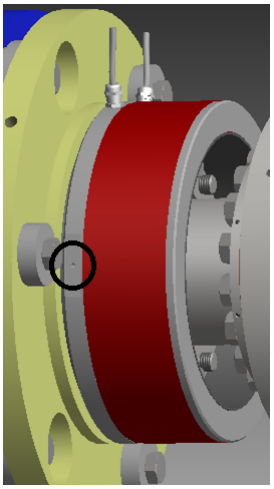


Figure 4.36: Hole in the slip ring.

A M5 screw will be placed in this hole. Also, at the end of each of the two horizontal profiles on the right side of the structure (the ones on the side that is hidden from view in the turbine, coloured in yellow in figure 4.37) a screw will be placed.

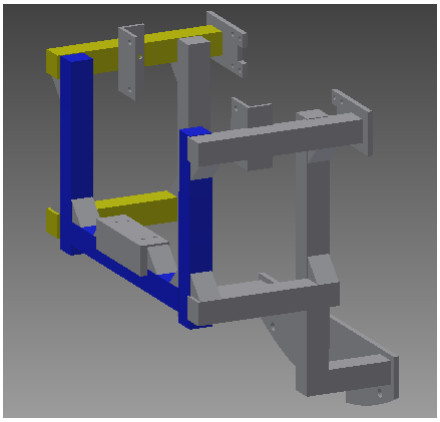


Figure 4.37: Profiles that will hold a screw at the end of their length.

This way, two simple ropes or strings attached from each one of the screws of the profiles to the screw in the slip ring will prevent the slip ring from rotating. It is also important to pay attention to the cables that come out from the slip ring, as if they get in contact with any rotating part they will be destroyed. That is why the horizontal profiles do not reach the position of the slip ring but they are somewhat shorter so that the rope or string will be tense and there will be no possibility for contact.

A basic explicative drawing is shown ahead in figure 4.38, the green lines being representative for the ropes or strings.

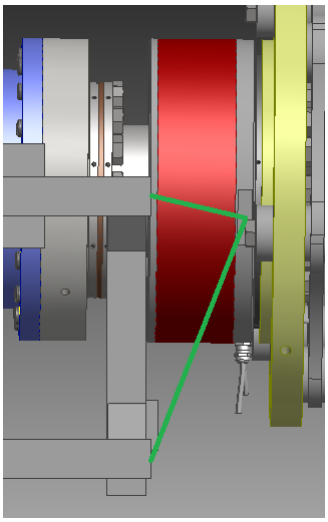


Figure 4.38: Ropes or strings system to keep the slip ring from rotating.

4.2.9 Final assembly and detailed design

In the end, after all the requirements have been fulfilled, the whole structure assembled with all the profiles and parts will be as shown in figure 4.39.

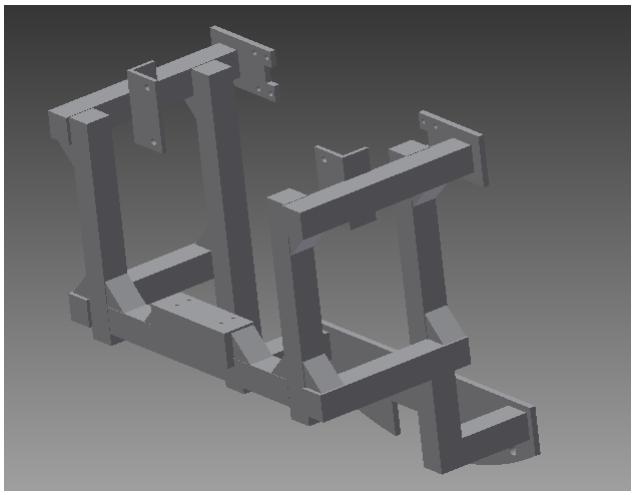


Figure 4.39: Final designed structure for the first position of the measurement systems.

Placed in the turbine together with the respective DLM sensors it will look like figure 4.40.

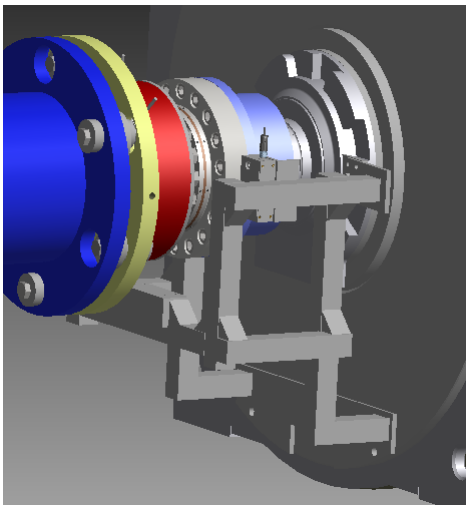


Figure 4.40: Final designed structure for the first position of the measurement systems placed in the turbine.

After having assembled the whole structure and having fixed it to the generator case the final result is shown in figure 4.41.

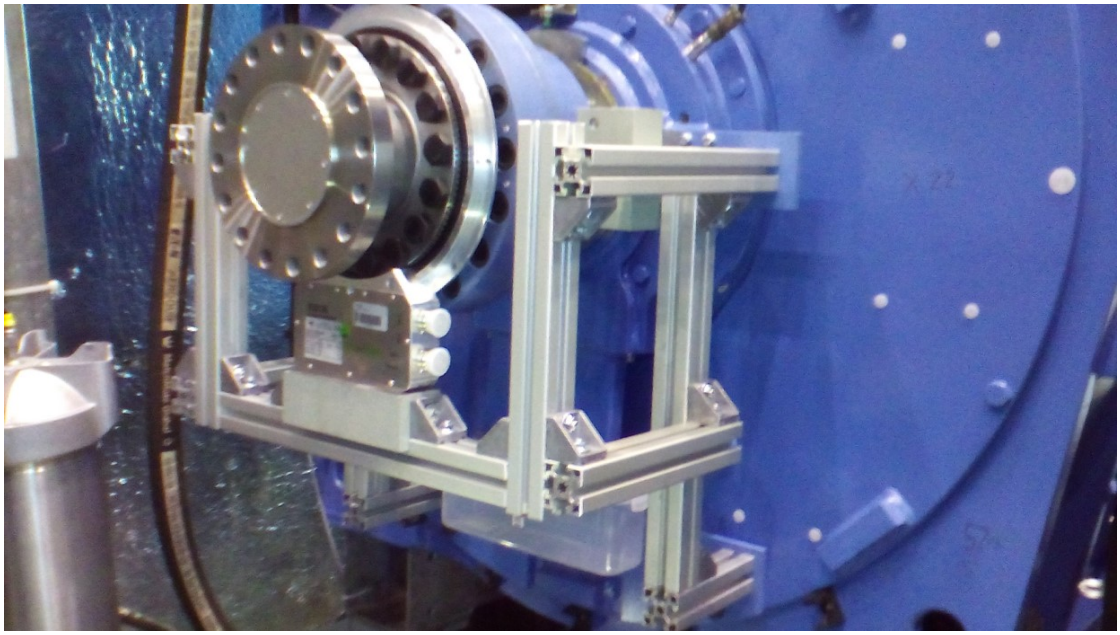


Figure 4.41: Final result in reality.

The list of parts and the technical drawings of the parts are placed in the annexes.

5 Design of the structure for the second position

As it was explained before, the other two measurement systems are placed in the main shaft, as far from each other as possible so that the displacement angle can be measured with accuracy.

The first of the two measurement systems placed on the shaft is the one placed closest to the gearbox. It is also required to have an appropiate geometry for the installation.

The chosen position is shown in figure 5.1.

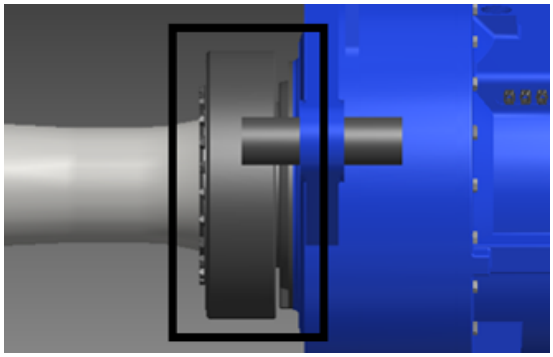


Figure 5.1: Second position for the installation of the sensors of the DLM system.

5.1 Design of the structure: Conceptual and embodiment design phase

The structure has to fulfill all the requirements set following the procedure of Pahl/Beitz for the DLM sensors. The same method as for the design of the first structure is followed.

5.1.1 First conceptual idea developed

First, a basic idea on how the structure will look like is developed. This first concept is evolved from two principles:

- The structure will be fixed to the case of the gearbox.

- The essential aim of the structure is to reach the position of installation of the sensors.

Following these criteria, a general idea for the structure is formed. This concept is shown in figure 5.2.

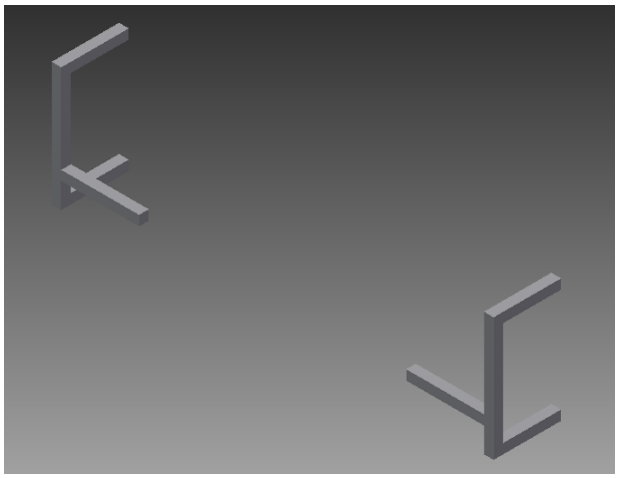


Figure 5.2: First evolved concept for the structure.

Attached to the gearbox case it will look like figure 5.3.

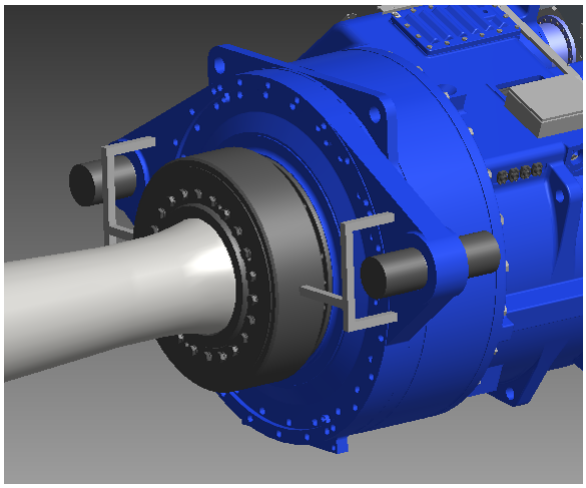


Figure 5.3: First evolved concept for the structure.

As the requirements for the structure are the same, stiffness and lightness, the structure will be built from the same kind of profiles as the first structure: rexroth aluminium strut profiles 45x45L.

5.1.2 Fixing points

After having developed a brief idea of the construction and having determined the profiles that are going to be used, what is most important to define is how the construction will be fixed to the case of the gearbox.

Having had a closer look at the location of the structure it is possible to determine different alternatives for the attachment. The options are considered and evaluated ahead:

- It is possible to drill some holes in the blue triangular parts which are placed at both sides of the shaft. See below figure 5.4.

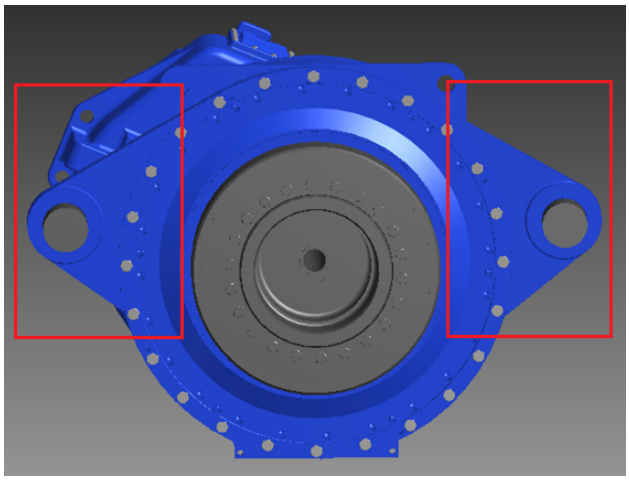


Figure 5.4: Blue triangular parts at both sides of the gearbox.

Drilling two threatened holes in each side a profile could be fixed in each of the drilled holes, and a structure similar to the first basic idea developed could be implemented. The problem is that the floor inside the nacelle is placed just in the middle of the triangular parts, making this option more complicated.

- It is possible to make use of the series of screws which are located all around the gearbox case fixing it to the gearbox. See below figure 5.5.

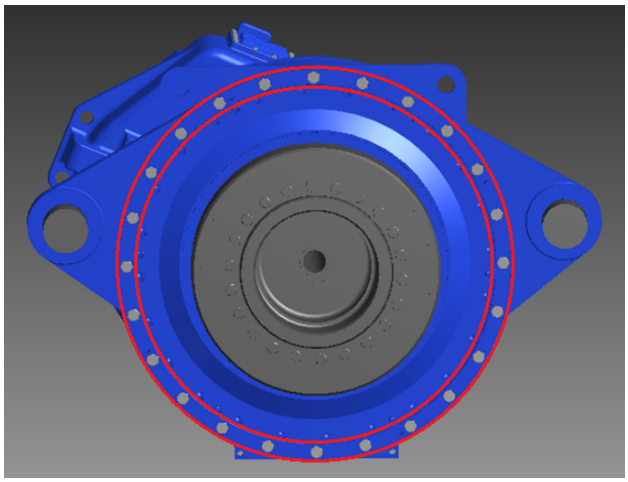


Figure 5.5: Series of screws around the generator case.

The same kind of system as before could be implemented, loosening two screws to insert a plate and then changing the screws for longer ones.

After an evaluation of all the possibilities, it is decided that the most appropiate fixing option is using the series of screws around the gearbox.

It is needed for the sensors to be placed at an angle between 170^{o} and 190^{o} degrees from each other, so the two structures have to be fixed at opposite sides of the shaft. Thus, it is possible to fix the two structures on the right and left side of the shaft or up and down.

As it was explained before, the floor inside the nacelle is placed in the middle of the gearbox, making it not possible to place the two structures on the right and left side of the shaft.

The final solution is using two screws over and two under the shaft as it is shown in figure 5.6.

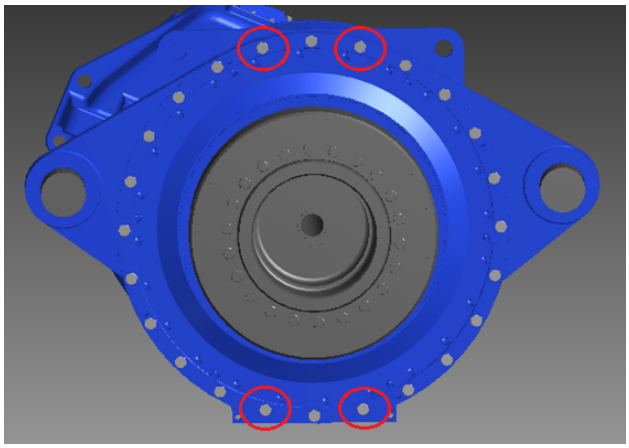


Figure 5.6: Screws used for fixing the structure.

5.1.3 Special parts designed for the fixing points

As described before, the four screws around the gearbox, two over and two under the shaft, are going to be used as fixing points and two exact structures will be fixed over and under the shaft.

Once the fixing points are chosen it is needed to think how the structure will be fixed to them.

Two identical plates will be designed for the screws over and under the shaft. A plate will be fixed to the gearbox and the profiles will be attached to it. If two plates were designed for each of the screws instead of a single one fixed with both screws, a tilting movement of the plates could happen. In order to avoid this possible displacement a single plate will be designed for both of the structures.

As it was said these M36 screws will be loosened and replaced for longer ones after the metal plate is placed. For this, it is needed to drill two holes with a 39 mm diameter in the plate, arranged at the same distance as the ones in the gearbox.

To fix the profile to the metal sheet a central bolt is once again used. The central bolt will be introduced in the profile, which has to be previously threatened. And the metal sheet will be located between the profile and the bolt.

Instead of a S12 screw, that is the one used when attaching two profiles, a M12 screw will be used as the load they can support is higher.

This way two M12x1.75 cylindrical screws with hexagon socket (DIN 7984) and 40 mm length will be used.

A 13 mm diameter through hole will be drilled in the metal sheet for the M12 screws. A H12 adjustment will be used as the profiles are being positioned. The hole in the center of the profile will also have to be drilled with a M12.

The shape of the metal plate will follow the contour of the gearbox not to interfere with other parts. One last detail has to be taken into account: it is needed to leave space for the screw which is in the middle of the ones we are using.

The metal sheet will finally look like the one in figure 5.7.

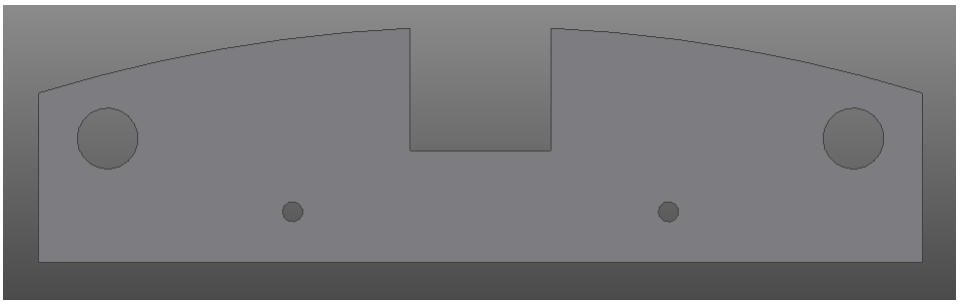


Figure 5.7: Metal sheet for the connection of the profiles.

5.1.4 Development of the shape of the structure

Once the fixing of the structure is defined, it is time to develop the rest of the structure.

It is needed to reach the position where the sensors have to be installed and provide the possibility of adjustment in the radial direction, as it was defined in the requirements.

This way, the structure shown in figure 5.8 is designed.

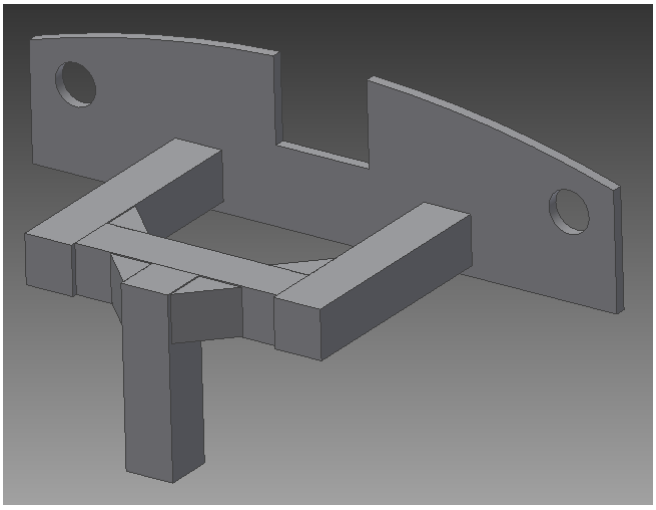


Figure 5.8: Designed structure to fix the sensors in their exact position.

It is necessary to make the horizontal profiles a bit longer than required, in order to leave a margin to adjust the position of the sensors on the direction of the axis. A calculation similar as the one described for the first structure is carried out and a safety net of 5 mm is left.

When fixed to the gearbox, the structure will look like figure 5.9.

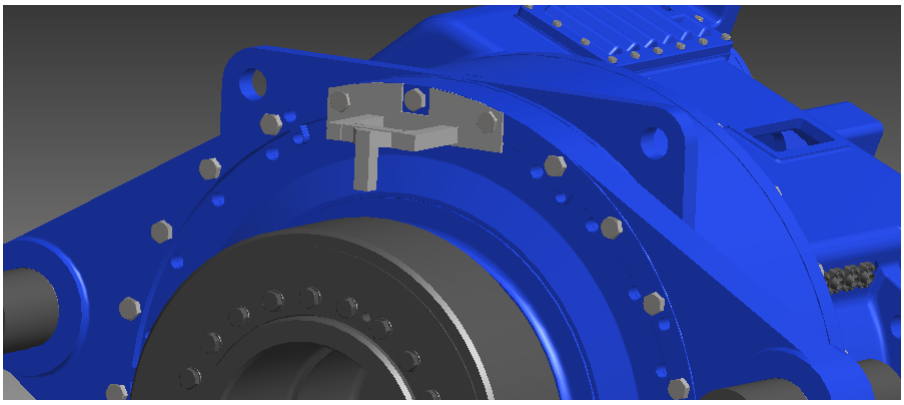


Figure 5.9: Designed structure to fix the sensors in their exact position assembled with the gearbox.

The profiles will be fixed again by the rexroth brackets in order to allow for possible adjustments.

5.1.5 Special part to fix the DLM sensors

Finally, the last step is to design the metal plate to fix the sensors to the profiles.

This time the holes of the sensors are in the same direction as the face of the profile, and the fixing can be made with a simple plate.

The plate will be a 10 mm thick metal sheet. Two screws and two t-nuts will be used to fix the plate to the profile, as was done before to fix the platew to the profiles in the first structure. Given that the profiles are 45x45, the respective t-nuts will have a 10 mm groove with M8 holes. Two M8x1.25 cylindrical screws with hexagon socket (DIN EN ISO 4762) and 12 mm length and two M8 stainless steel T-nuts will be used. In the metal plate two through holes with 9 mm diameter will be drilled, separated 25 mm from each other to leave space for the length of the T-nuts (20mm).

To fix the plate to the profile the holes of the sensor housing will be used, for this, two M10x1.5 cylindrical screws with hexagon socket (DIN 7984) and 50 mm length will be used and two through holes of a 10.5 mm diameter will be drilled in the metal plate arranged in the same disposition as the holes in the sensor housing.

This time it is very important to take into account the radial alignment required, 90 ± 1^{o}.

In the fixing of the connection plate to the gearbox and in the fixing of the profiles to the connection plate there can be some angular displacement. It is important to calculate this displacement and provide an appropiate system in the fixing of the sensors that can compensate it. For this, in the fixing of the plate to the profiles, the upper hole of the plate will be left as a normal hole, and in the second one a slot will be drilled in order to allow for the necessary compensation of the radial alignment, as it is shown in figure 5.10.

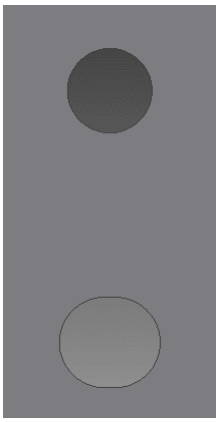
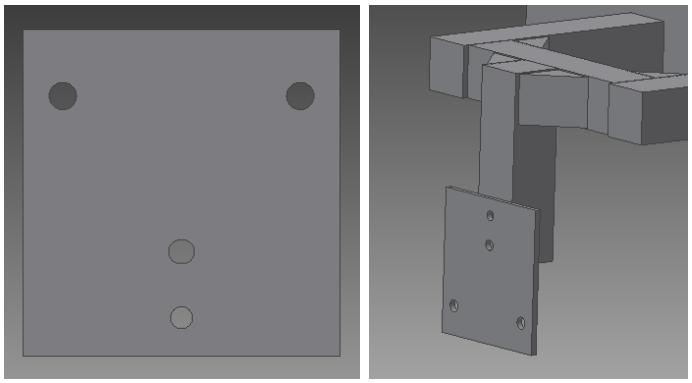


Figure 5.10: Hole-slot system.

A calculation is carried out and the different angular displacements are determined. First there is a displacement of 0.2574^{o} between the hole for the M36 screws of the generator and the M36 screws and then 0.2563^{o} between the M36 screws and the hole for the M36 screws on the connection plate. Also, there is a displacement of 0.17^{o} between the connection plate and the horizontal profile. In total this makes around 0.7^{o}, that are translated into a necessary slot of 0.3054 mm and adding a safety net a total slot of $\pm$ 0.5 mm will be drilled.

This way the plate will look like the one in figure 5.11.



(a) Designed metal plate. (b) Location of the metal plate.

Figure 5.11: Plate for designed to fix the DLM sensors.

As it can be seen in the image, it is also possible to adjust the position of the sensors in the radial direction just by moving the plate and fixing it again to the vertical profile in the proper position.

5.1.6 Final assembly and detailed design

In the end, after all the requirements have been accomplished, the whole structure assembled with all the profiles and parts will be the one shown in figure 5.12.

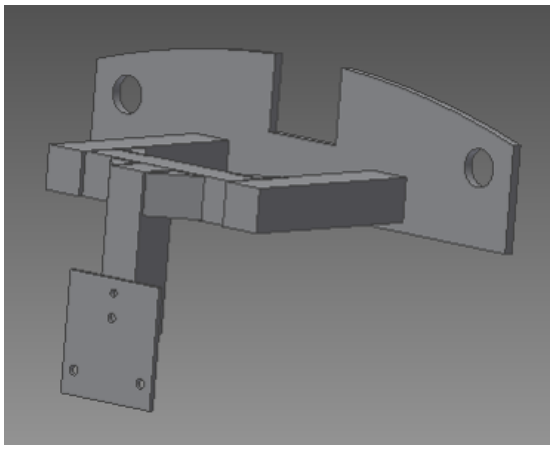


Figure 5.12: Final designed structure.

Placed in the turbine together with the respective DLM sensors it will look like figure 5.13.

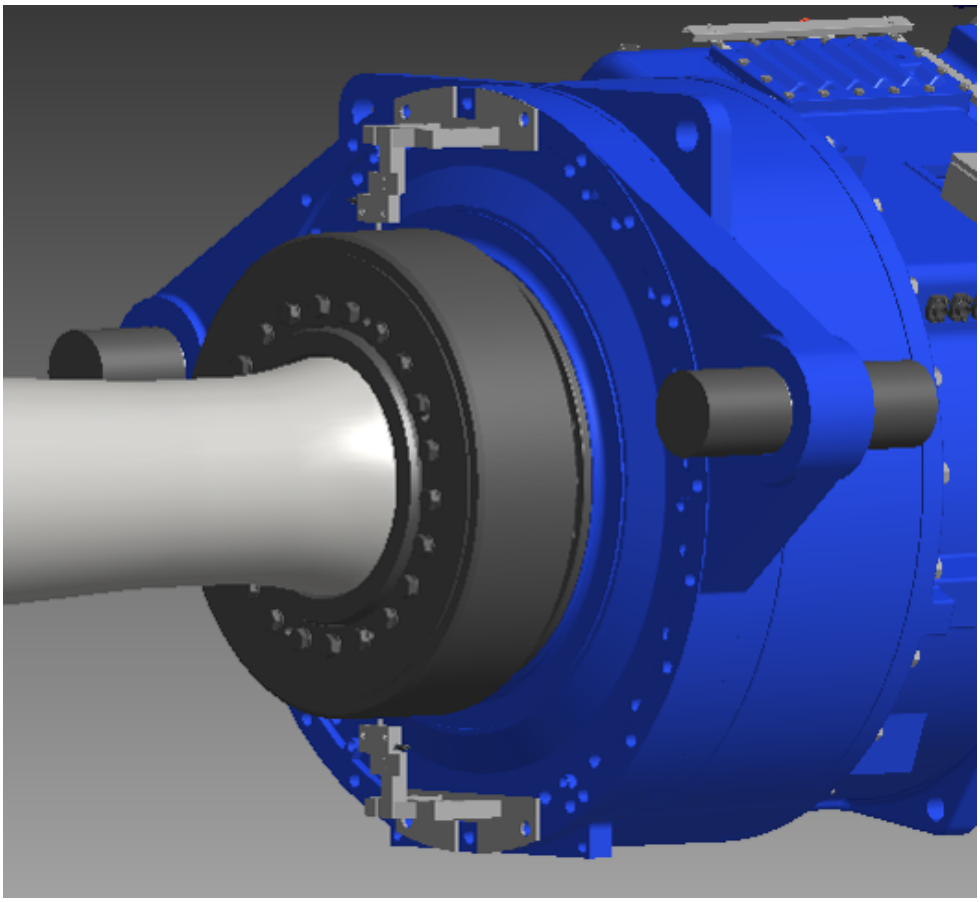


Figure 5.13: Final designed structure in the whole turbine.

The list of parts and the technical drawings of the parts are placed in the annexes.

6 Design of the structure for the third Position

As it was explained before, two measurement systems are placed in the main shaft as far from each other as possible so the displacement angle can be measured with accuracy.

The first of the two measurement systems placed on the shaft was the one just developed that was located close to the gear box. This makes this last measurement system to be located in the main shaft, close to the front part of the turbine. Again it is required to find an appropiate geometry for the installation.

The chosen position is shown in figure 6.1.

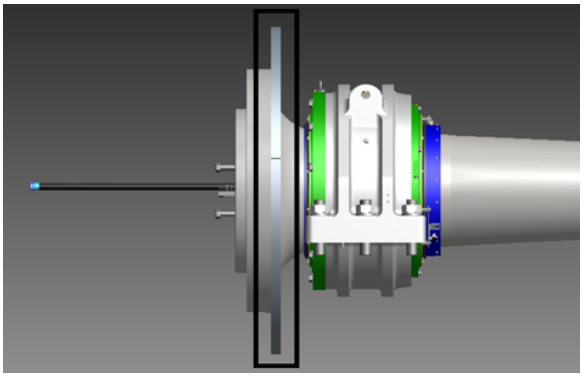


Figure 6.1: Third position for the installation of the sensors of the DLM system.

6.1 Design of the structure: Conceptual and embodiment design phase

The structure has to fulfill all the requirements defined following the procedure of *Pahl/Beitz* for the DLM sensors. For the design of the structure for the installation of the DLM sensors in this position, is very important to take into account the space restriction. As the sensors are going to be placed at the very front of the turbine, the nacelle is very close to the components and there is only a narrow space left for the installation. The same method as the one used for the design of the others structures is followed.

6.1.1 First conceptual idea developed

As done with the other measurement positions a basic idea on how will the structure look like is first developed. This primary concept is evolved from two principles:

- The structure has to be fixed to a stiff and not rotating part close to the chosen position for the installation of the sensors.

- The essential aim of the structure it is to reach the position of installation of the sensors.

Following this criteria, a general idea for the structure is formed. The structure will basicly consist of two identical arms from where the sensors will be fixed.

6.1.2 Fixing points

The most difficult point for the design of this structure is the determination of the fixing points. As it was mentioned before the space between the components and the nacelle is very narrow and makes it difficult to install the arm. There are different possibilities that have to be considered:

- Fixing the structure from the nacelle. This is not a viable solution as the nacelle is not rigid enough.

- The other possibility is to fix the structure from the following component of the turbine shown in figure 6.2.

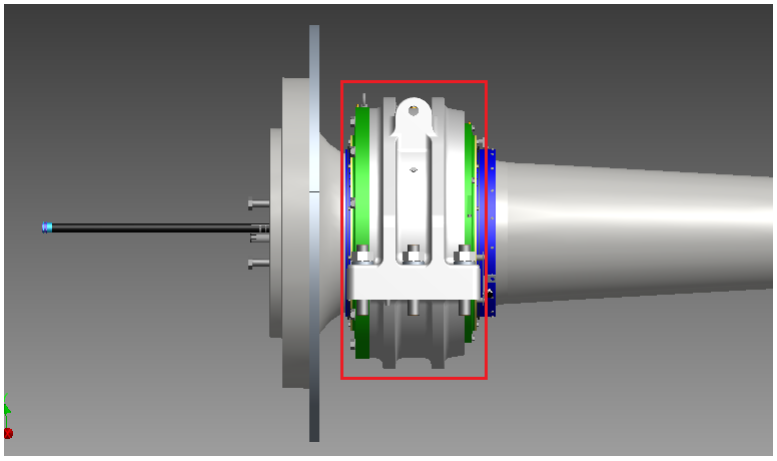


Figure 6.2: Component from which to fix the structure.

Now it is to determine how to fix the structure to this component. Holes can be drilled on the component and from them the arm can be fixed. Different options have been considered for this purpose:

- Drilling a hole on the straight part of the first nerve of the component is not possible as there is not enough space for the drilling tool. See below figure 6.3.

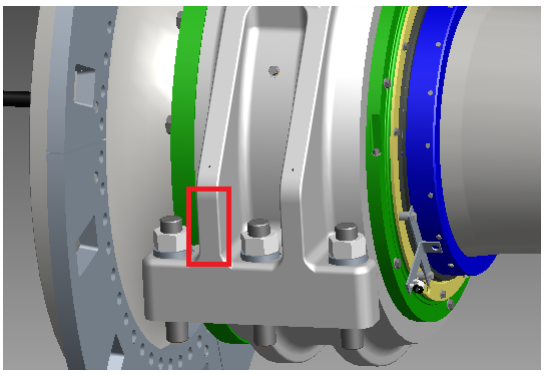


Figure 6.3: Straight part of the first nerve

- Drilling a hole on the straight part of the second nerve is possible, but with an only fixing point the arm will not be properly fixed and it will not be rigid enough. See below figure 6.4:

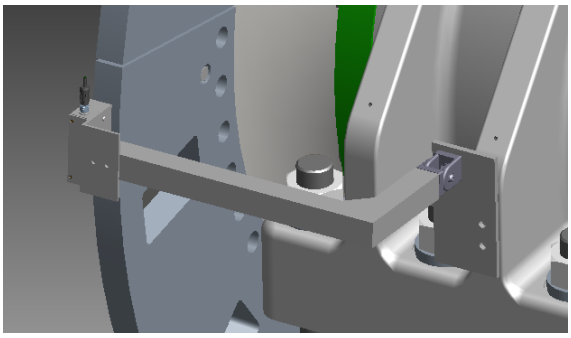


Figure 6.4: Arm not rigidly enough fixed on the second nerve of the component.

- Another possibility consists on drilling holes on the sloped part of the nerves. By drilling a hole in each one of the nerves and fixing the arm to both of them, the arm will be rigidly fixed.

After an evaluation of this possibilities the third option is chosen, but it has to be assured that drilling a hole on the nerve is possible and will not affect the rest of the turbine components.

The arm will be directly attached to the nerves by means of the drilled holes. The holes will be drilled on the sloped part of the nerve as below as possible so the profile is closer to the required position of the sensors. A M12 threatened hole with a length of 25 mm will be drilled on each nerve. See below figure 6.5.

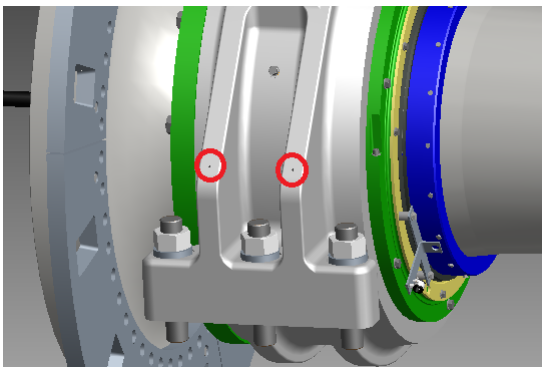


Figure 6.5: Drilled holes on the nerves.

The profiles will be attached to the nerves using two M12 central bolts with a length of 30 mm. In the profile two 9.8 mm diameter holes will need to be drilled in order to allow access for the fastening tool.

6.1.3 Development of the shape of the structure

After having defined the fixing points of the arm, the shape of this arm is developed. In this case the most difficult requirement to achieve is that the sensors have to be placed on opposites sides of the shaft forming an angle of 180 $\pm 10^{o}$, but the arms are not fixed at an appropiate position that fulfills this requirement as the structures for the other two previous positions.

Also, the floor of the nacelle has to be taken into account, as it is placed almost in the middle of the shaft.

In order to fulfill these two conditions, the sensors will be placed 4.7^{o} over the middle of the shaft, what means that the sensors will be placed 170.6^{o} from each other, as shown in figure 6.6 .

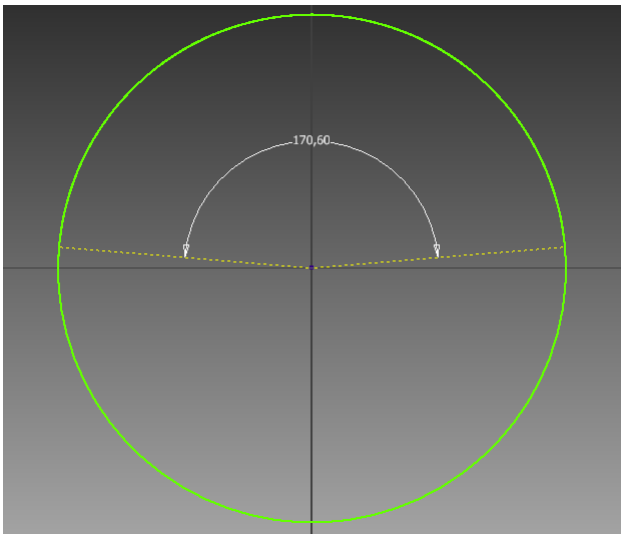


Figure 6.6: Defined position of the sensors.

Having defined the position of the sensors the rest of the structure can be developed. The structure will look like the following figure 6.7:

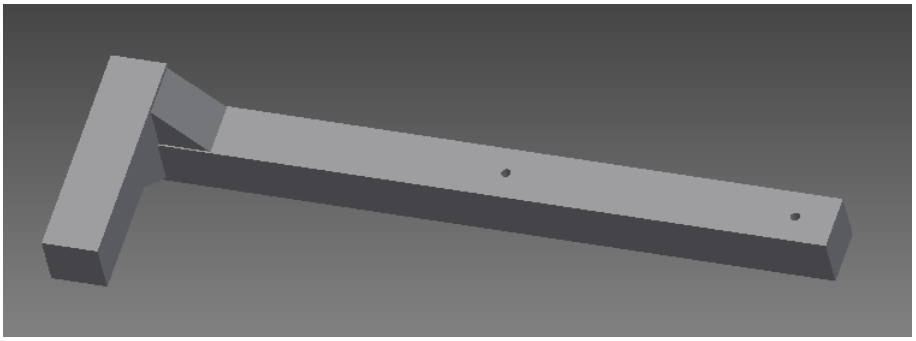


Figure 6.7: Developed arm for the third measurement position

6.1.4 Special part to fix the DLM sensors

The sensors will be fixed to the profiles from the holes of the sensor housing to a 10 mm metal plate. In order to leave some space between the component were the sensors are going to be installed and the arm, the fixing of the sensors to the metal plate will be made by longer screws guided to the metal plate with two metal tubes. See below figure 6.8.

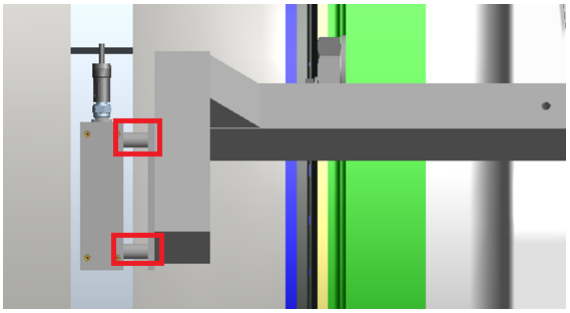


Figure 6.8: Metal tubes to guide the screws.

A 2 cm space will be left so the metal tubes cover it. They will be a 10.5 mm inner diameter with a 1 mm of thickness.

The 10 mm metal plate will be design to achieve the exact position of the sensors.

The same way as for the other measurement positions, the metal sheet will be fixed to the sensors with two M10x1.5 cylindrical screws with an hexagon socket (DIN 7984), only that in this case with a lenght of 70 mm (20 mm more than in other cases to cover the space left). In order to allow for possible adjustments in the radial direction, two slots of ± 1 mm and 10.5 mm diameter will be drilled arranged at the same disposition as the holes in the sensor housing. An H12 adjustment has been chosen, as the holes are used for positioning.

For fixing the plate to the profile, two screws and two t-nuts will be used. As the profiles are 45x45 the respective t-nuts have a 10 mm groove with M8 holes. Two M8x1.25 cylindrical screws with hexagon socket (DIN EN ISO 4762) and 12 mm length and two M8 stainless steel T-nuts will be used. In the metal plate two through holes with 9 mm diameter will be drilled, arranged at the exact position to achieve the 4.7^{o} over the middle of the shaft.

Finally the metal sheet will look like the following shown on figure 6.9:

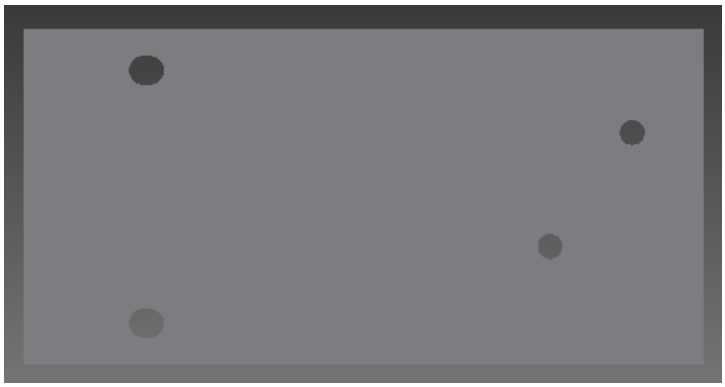


Figure 6.9: Metal sheet for fixing the sensors

6.1.5 Final assembly

In the end, after all the requirements have been fulfilled, the whole structure assembled with all the profiles and parts will be as shown in figure 6.10.

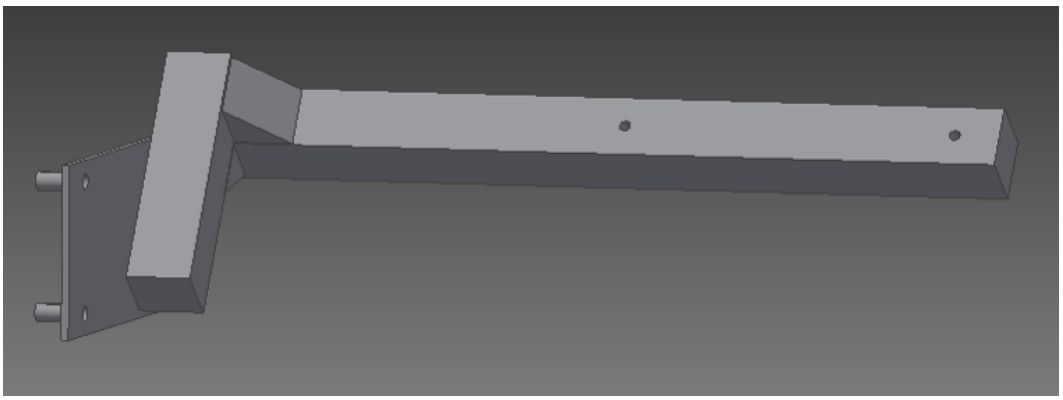


Figure 6.10: Final designed structure.

Placed in the turbine together with the respective DLM sensors it will look like figure 6.11.

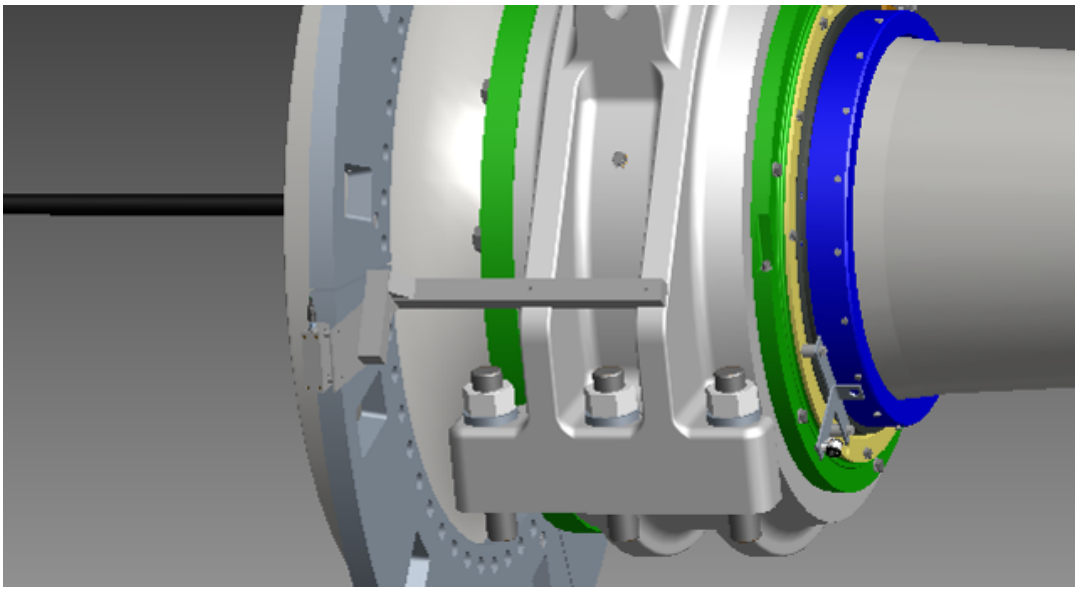


Figure 6.11: Final designed structure placed in the turbine.

It is important to remark that the viability of this solution has to be confirmed as it has to be assured that is possible to drill the M12 holes in the nerves of the component mentioned before.

7 Summary and conclusions

Wind shear and turbulence as well as resonance vibrations generate high dynamic loads on the components of a wind turbine. The Dynamic Load Monitor system measures the rotation speed and torque in the drive train, and by comparing the actual loads with the design loads of the major components, important information to estimate the residual life of these components is obtained. This way, it is possible to avoid overloads and damages before they influence the lifetime of the major components, bringing down service costs and ensuring higher energy yields by adjusting the operating conditions of the turbine.

The DLM system, the condition monitoring system used in this case, consists of a Sensor Control Unit, which will be mounted in the nacelle, and three measurement positions, each of them consisting of one steel tension strip mounted like a waist belt on the shaft and two sensors.

Two of the measurement systems will be mounted on the main shaft, one in the front of the turbine and the other one close to the gear box. The third measurement will be placed on the fast shaft close to the generator.

The installation of the sensors of the measurement systems at their exact position is the objective that was pursued in this thesis. For the design process of this structures the systematic approach defined by Pahl/Beitz was followed.

The first step in the design process consists on the clarification and specification of the task. For this, all the requirements that have to be fulfilled for the installation of the sensors were defined and classified between demands and whises.

As the sensors of the DLM system have to be placed in a very exact position around the defined locations of installation, a whole structure had to be developed in order to install them with accuracy at the required positions.

After the definition of requirements, the conceptual design phase starts. A crucial point for these structures was the definition of their fixing points to the turbine. It was necessary to analyse and evaluate all the different fixing possibilities and choose the most suittable and rigid one.

Once this point was defined, the rest of the structure was designed following the requirements previously set. Every demand has to be fulfilled so the sensors can later obtain accurate measurements. It is also important to allow a certain margin of flexibility for the positioning of the sensors, in case some of the measures taken from the turbine are not precise.

A basic idea of the structure was developed, and from it different variants for all the features forming the structure were proposed. Each of them was considered and evaluated in order to choose the simpler but more addecuate and stiffer solution.

Once a solution was chosen the embodiment design took place. A definitive layout for all the features was developed and it was checked that with that solution all the requirements were met.

Finally, a detailed design of the defined structure was carried out, generating the final design drawings which will be used to manufacture all the parts forming the structures.

References

[Hyt] *Hytecgroup, connection elements*. http://www.hytecgroup.co.za/uploads/bulkpdf/Connectione

[Ins] *Installation manual for Dynamic Load Monitor*. Bosch Rexroth AG

[Man] *Manual F23iS Torquemeter*. GIF mbH

[A 2000] A, Bossanyi E.: *The Design of Closed Loop Controllers for Wind Turbines*. Bd. 3. John Wiley and Sons, 2000

[Hau 2008] Hau, Erich: *Windkraftanlagen*. Bd. 4. Springer-Verlag Berlin Heidelberg, 2008. http://dx.doi.org/10.1007/978-3-540-72151-2. http://dx.doi.org/10.1007/978-3-540-72151-2. – ISBN 978–3–540–72150–5

[Pahl u. W.Beitz 1988] Pahl, G. ; W.Beitz: *Engineering design: A Systematic Approach*. The Design Council London, 1988. – ISBN 0 85072 239x

[Sharma u. Mahto 2013] Sharma, Sachin ; Mahto, Dalgobind: *Condition Monitoring of Wind Turbines: A Review*. Bd. 4. International Journal of Scientific and Engineering Research, 2013

[Sheng u. Veers 2011] Sheng, Shuangwen ; Veers, Paul: *WIND TURBINE DRIVETRAIN CONDITION MONITORING – AN OVERVIEW*. National Renewable Energy Laboratory, 2011

[Vath 2013] Vath, Andreas: *Reliability and Energy Yield Increase of Wind Turbines as a Benefit of Dynamic Load Reduction Operation*. Bosch Rexroth AG, 2013