MAS513-Advanced Robotics project:

Online health status detection of a motor

PROBLEM: Is it possible to determine the health status of the motor continuously using non-contact sensors and non-destructive testing?

Gianluca Salata, 25/08/2021

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State of art:

The most common technique for the detection of the health status use contact sensor like as
- Vibrometer/accelerometer
- Voltmeter and ammeters

All of them are base on the key concept that:

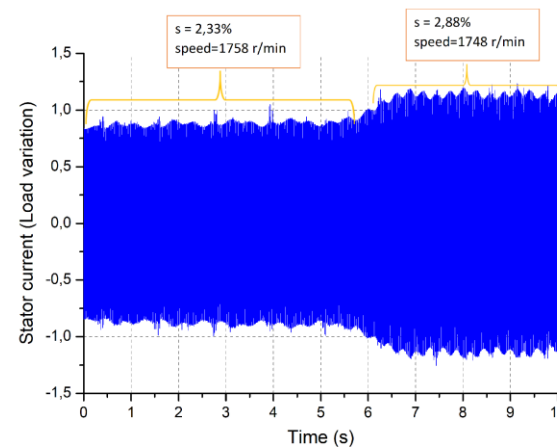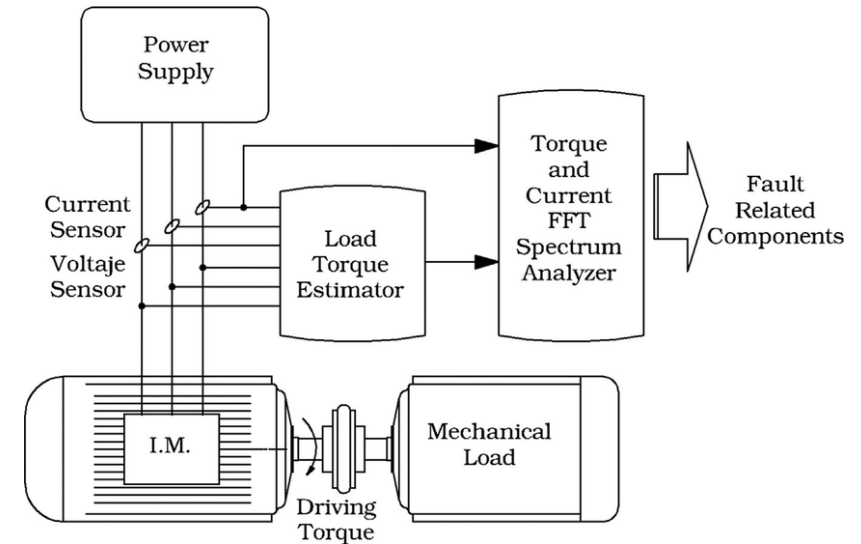==Each fault is related to a precise harmonic in the spectrum==

1) **MCSA(motor current signature analysis)**

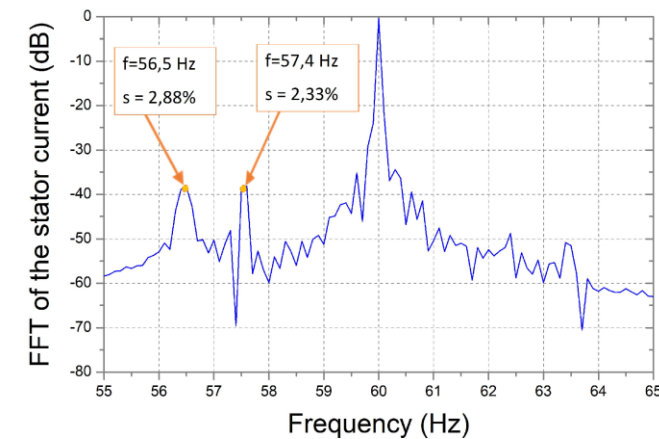This method require to measure the variation of the absorbed current from the motor.
From the current spectra is able to identify motor's fault thanks to a specific relationship.
For example, the frequency related to an air gap(eccentricity):

$$f_{ecc} = \left\{ (R \pm n_d) \left(\frac{1-s}{p} \right) \pm n_{\omega s} \right\} f_0$$

(a) Stator current variation

(b) Motor Current Signature Analysis (MCSA)
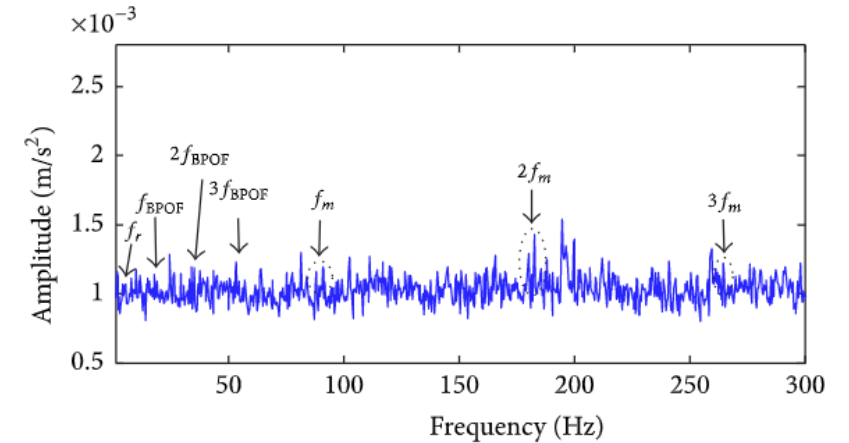
2) Vibration analysis

Usually It is based on 3-axis MEMS accelerometers that measure the vibration of the shaft. Also in this case is possible to find fault analysing the spectrum of the displacement of the shaft.

An outer race bearing defect is related a to the characteristic frequency:

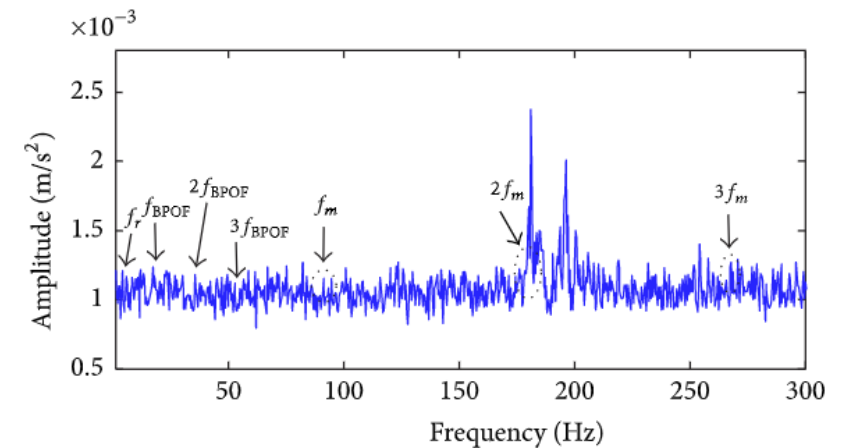$$f_{oD} = \frac{n}{2} f_{rm} \left(1 - \frac{BD}{PD} \cos \phi\right)$$

⚠️ Requires bearing's geometry

(a) Healthy condition

(b) Bearing defect

State of art:

MCSA	*Vibration analysis*
non-invasive	independent of the type of motor power supply
Easy to implement	low power consumption
low signal-to-noise ratio	Lower realiability
contact-sensors	contact-sensors

Project's aim

The aim is to determine the continous health status of the motor using a Lidar that measure the vibration of the shaft.

PROS:
- Non intrusive monitoring system
- Mostly independent from enviroment condition
- Retrace the fault

CONS:
- Exspensive
- More complex

Assumptions:
1) Only one fault can occur for each run (NO multiple-fault diagnosis)
2) Only air between the Lidar and the target
3) Consider only one direction vibration

PC

Fault …

Process

CWFM Lidar generates a voltage signal

↓

Acquisition

↓

Filtration

↓

Fourier trasformaton o of the signal to obtain the range o the shaft

↓

Analysing harmonics of the displacement to detect known fault

Validations of known equation injecting known fault

PC
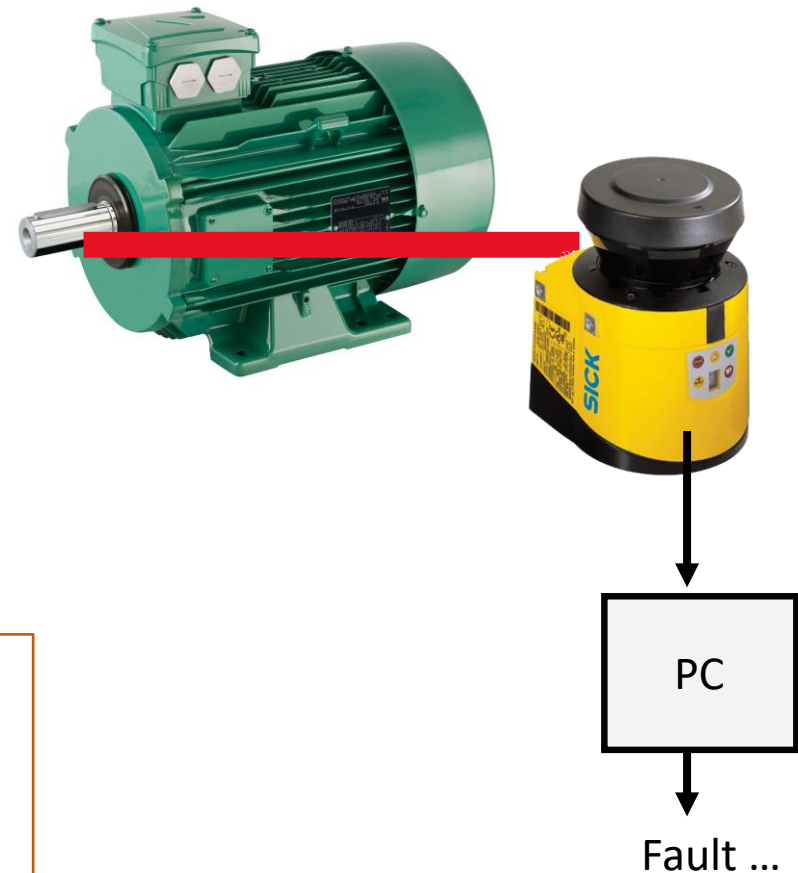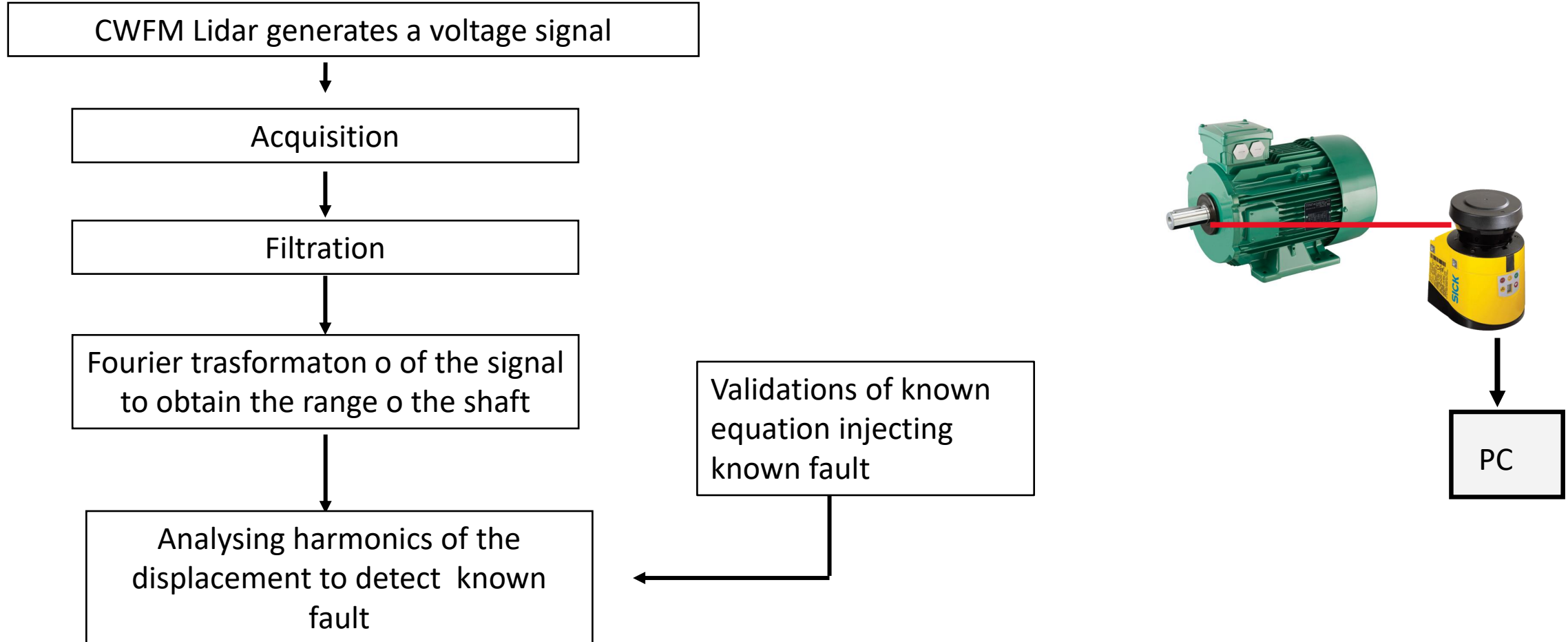
Equipment

Induction motor with variable load
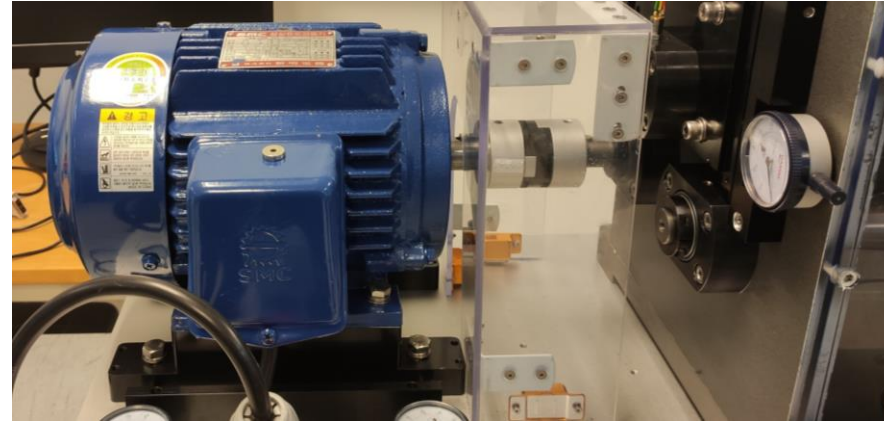
LIDAR LMS133 -10100

Datasheet: here

The project can be improved introducing multiple-fault diagnosis and multi axes measurements.

Condition monitoring without contact with the object can be very useful when the motor is placed in hostile or not very accesable enviroment.

The data from the sensing components can be used for the control system of the motor, improving efficiency.

Thanks for the attention!

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Continuous health status detection of a motor

1. **Excellence**

   1.1. **State of art, knowledge needs and projects objectives:**

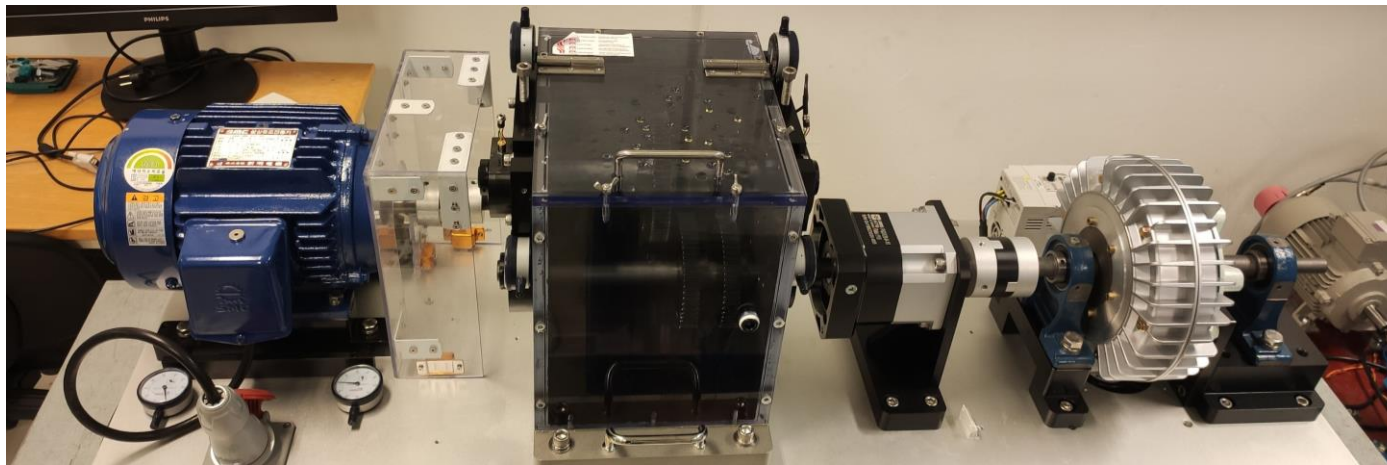   Nowadays, timely maintenance of electric motors is vital to keep up the complex processes of industrial production. Causes of motor failures are different: bearing faults, insulation faults, and rotor faults, misalignments etc. Early detection of these faults allows replacement of the components, rather than replacement of the motor.

   Determine the continuous health of a motor can be useful to predict a failure and to enable some procedures to put the motor into safety condition. This can also help the engineer to be aware of the type of the failure.

   Actually most technique use contact sensor; the most popular for the detection of faults in induction motors with contact sensors are: the MCSA (motor current signature analysis) and the analysis of vibration signals. The MCSA technique involves the analysis of stator current signals collected with a current clamp or an ammeter. It is based on the recognition that an electric motor (ac or dc) driving a mechanical load acts as an efficient and permanently available transducer by sensing mechanical load variations and converting them into variations in the induced current generated in the motor windings. These motor current variations are carried by the electrical cables processes as desired. Motor current signatures, obtained in both time and over time to provide early indication of degradation. The signal acquisition can be carried out during either a start-up transient or a steady-state regime of the induction motor. For signals acquired during a steady state, it is expected that the frequency content remains time invariant, and the analysis is performed with methods that provide efficient frequency decomposition with good tolerance to low signal-to-noise ratio. The most common technique in the analysis of stationary signal is the Fourier transform. However it has the disadvantage of a limited frequency resolution, the spectral leakage, and a low noise tolerance. If the motor operates in non-steady regime, several processing methods have been proposed: the signal could be analysed by time-frequency decomposition method such as the short time Fourier transform, the discrete wavelet transform, the continuous wavelet transform etc . The combined use of some this technique with an artificial intelligence helps to determine components or signatures that are present in the signals for identifying faults and their severity [1].

   In order to diagnose motor faults, MCSA uses the current spectra, which contains potential information of motor faults. Therefore, it is important that abnormal harmonic frequencies are independent of the types of drive-systems or control techniques. Because of this property, MCSA is more useful than any other online motor diagnosis techniques.

   Each fault is related to a precise harmonic in the current spectra; for example, a bearing failure cause the variation of air-gap length when a rotor turns. Since this variation comes from the defective structure of a ball bearing, the abnormal harmonic frequencies of a ball bearing can be derived from the bearing model [2]. The related frequency is:

   $$f_{bearing} = f_0 \pm n_b f_{i,0}$$

   $$f_{i,0} = \frac{n}{2}(1-s)f_0 \left\{1 \pm \frac{\text{BD}}{\text{PD}} \cos \beta \right\}$$

   Where n_b is the number of balls, PD is the bearing-pitch diameter, BD is the ball diameter, β is the contact angle of crack on races, and n is the positive integer, f_0 is the electrical supply

frequency, s is the per-unit slip respectively. However, bearing parameters PD, BD, and β, cannot be easily detected; the manufacturer should supply that geometries in the datasheets. Also an misaligned shaft, due to an unbalanced load or a worn bearing, can cause an air-gap eccentricity in the motor. The air-gap eccentricity includes static and dynamic eccentricity; the last one appears when the rotor centre is not located at the rotation centre.

It has been shown that both static and dynamic eccentricity give rise to abnormal harmonic frequencies in a stator current given by [3]:

$$f_{\text{ecc}} = \left\{ (R \pm n_d) \left(\frac{1-s}{p} \right) \pm n_{\omega s} \right\} f_0$$

where R is the number of rotor slots, $n_d = \pm 1$ is the eccentricity-order number, and $n_{\omega s} = 1,3,5,...$,the stator MMF-harmonic rank, respectively.

Another way to determine the health status of a motor is the vibration analysis. It is based on the signal coming from accelerometer/vibrometers positioned on the crankshaft; 3-axis MEMS accelerometers are frequently used due to its ability to measure vibration at very low frequency, around 0Hz. Through the spectral analysis of the shaft-vibration is possible to determine the presence of fault inside the motor. The bearing fault related vibration frequencies are easily calculated with known bearing geometry and rotor speed [4]. The vibration frequencies show up also in the current spectrum as the modulation frequencies, therefore it is possible to provide continuous monitoring using motor current data, as in MCSA analysis, instead using crankshaft's vibration data.

Bearing faults such as outer race, inner race, ball defect, and train defect cause machine vibration and it results in air-gap eccentricity. These defects have vibration frequency components, f_v, that are characteristic of each defect type. The outer race defect frequency is:

$$f_{\text{oD}} = \frac{n}{2} f_{rm} \left(1 - \frac{\text{BD}}{\text{PD}} \cos \phi \right).$$

where f_{rm} is the rotor speed in revolutions per minute.
The inner race defect frequency is:

$$f_{\text{ID}} = \frac{n}{2} f_{rm} \left(1 + \frac{\text{BD}}{\text{PD}} \cos \phi \right).$$

Ball defective frequency is given by:

$$f_{\text{BD}} = \frac{\text{PD}}{2\text{BD}} f_{rm} \left(1 - \left(\frac{\text{BD}}{\text{PD}} \right)^2 \cos^2 \phi \right).$$

Cage defect frequency, caused by irregularity in the train, is given by:

$$f_{\text{CD}} = \frac{1}{2} f_{rm} \left(1 - \frac{\text{BD}}{\text{PD}} \cos \phi \right).$$

There is a relationship between the characteristic frequency of a fault in the current spectra and the vibration spectra. The characteristic current frequencies, f_{CF}, due to bearing characteristic vibration frequencies are calculate by

$$f_{\text{CF}} = |f_e \pm m f_v|.$$

where f_v is the vibration frequency components of the fault and f_e is the power system frequency.

The others parameters are relate to the geometry of ball bearing and is shown in the figure 1 below:
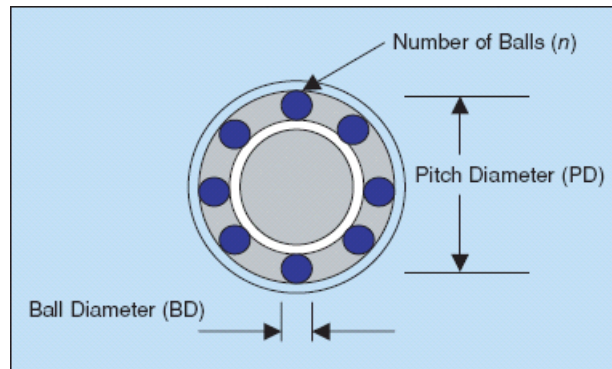

Figure 1 credits to [4]

All these techniques for fault diagnosis have advantages and disadvantages.

The MCSA technique has the advantages of being non-invasive, easy and cheap to implement, providing good results in fault diagnosis; however, under certain conditions its application is not sensitive enough because it has a low signal-to-noise ratio. In the other hand, vibration analysis has the advantage that its results are independent of the type of motor power supply, high reliability, low power consumption, low cost and yields good results, but its implementation requires using accelerometers as the basic sensors that must be placed near or on the motor, which sometimes is difficult to achieve.

To partially solve the problem of using only contact sensors, Paulo and Daniel [5] proposed to detect fault through sound and vibration signals; in fact the sound is a physical phenomenon that provides information about the behaviour of a system and can be used as a parameter for determining the condition thereof. The acoustic sound waves contain information about the health status of the machine because sound is produced by mechanical vibrations. The electric motor is not an exception, and the vibrations generated by defects in bearings, mechanical unbalances and broken rotor bars produce sounds with characteristic frequencies associated with each fault.

However the downside of sound signal analysis is its sensitivity to external noise , which should be avoided whenever possible; this limits enormously the application of this technique. The diagnosis through the analysis of acoustic sound signal is a first non-invasive method using non-contact sensor, a microphone in this case, to check the motor's status.

Vibrations are a key factor to determine the health of a motor. This project wants to determine the amplitude of the vibration of the shaft using a Lidar and analysing the presence of harmonics inside of the displacement is possible to retrace some known fault. McFadden [6] and M. J. Devaney [4] describe that every superficial defect of the mechanical components is related to a specific frequency that is proportional to the speed of the shaft, as reported before. But also other defects, specific for induction motor (most common type of motor in the industry), have typical harmonics in the spectrum.

1.2. Research question and hypothesis, theoretical approach and methodology

The development of the project is based on different research questions. Using a Lidar, it is necessary to determine the correct distance between the sensor and the shaft. Also, how it is possible to determine the amplitude of the displacement of the shaft while the motor is working. The presence of a load attached to the shaft can disturb the readings, if the load is unbalanced.

In a system with multiple-fault conditions present, such as broken rotor bars (BRBs), unbalance (UNB), and bearing defects (BDs), it is important to distinguish between the faulty conditions, [7]. When multiple faults exist, vibration and current are excited by several fault-related frequencies combined with each other, linearly or nonlinearly. Since multiple-fault situations may occur in the induction motor, a wrong conclusion may be drawn in the diagnosis based on the partial fault signature. Therefore, multiple-fault diagnosis is still a big challenge in the research of monitoring and maintenance of induction motors. This project considers that only one fault can occur in the motor for each run-time. Otherwise, as described in [7], the analysis of the vibration's spectrum become more complex; the main scope is to use a non-contact sensor to determine the health status, so the project is mainly focused on the acquisition part of the entire system and the signal processing.

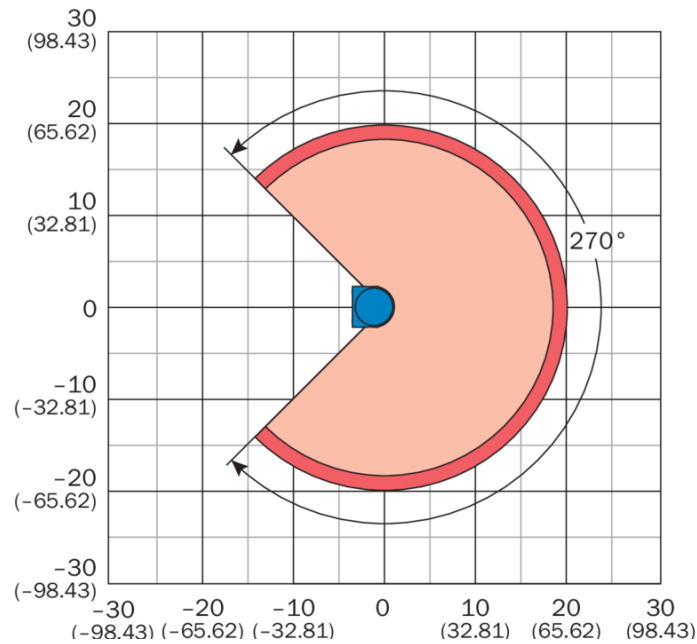The project workflow will be divide in different steps.

1)*Set appropriately the Lidar's parameters and the communication between the sensor and computer.*
For this project Sick 2D lidar is going to be used, in particular the LMS133, that it has an aperture angle of 270° horizontal with a frequency of 50/25 [Hz], and a very large range of detection (20 [m]), as default.

Figure 2: Lidar LMS133-10100

However this parameters need to be changed for the objective: reducing the aperture angle to few degrees because the aim is to monitor the distance of a specific point in the 2D plane with high accuracy, related to the shaft. Furthermore reducing the angle is possible to increase the frequency. The Lidar must be located near the shaft but not too much, following the SICK datasheet it has a minimum measuring distance of 0.5 [m].

The Lidar communicate with a computer, in this case a Jetson nano, through an ethernet cable thanks to the specific ROS package made by lidar's manufacturer; using ROS there is more flexibility in data manipulation so the distance data coming from Lidar can be process thanks to specific node created appropriately to the final scope. The message sent by the lidar is binary to reduce the traffic in the communication line, so a ROS node need to translate the binary code into a numerical number that can be easily processed.
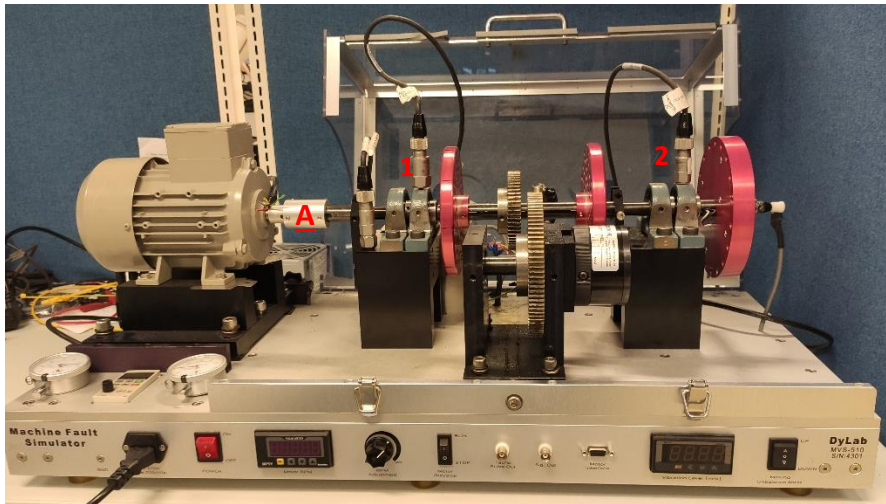
2) *Execute the fourier transform of the signal*
The signal will be noisy and can affect the output of Fourier transformation: one practical way to reduce noise is to apply retro-reflective tape to the target shaft to improve the measuring quality. The other way, more effective, is to filter the signal, the distance signal will be filtered using a band-pass filter to reduce white noise and the frequency range starts from the lowest detectable frequency possible which is related to the shaft's speed.
In order to execute the FFT of the signal, there will be used a python code that collect a specific amount of values coming from the Lidar and calculate the FFT. While it is doing that a new set of that will be collected so is possible to re-calcualted the FFT and updating the amplitude of harmonics in an apparent real time, because a fault could be detect if, at a specific frequency obtained using formulas described above, the harmonics has big amplitude in comparison to the amplitude at normal condition.

3)*Set the experimental setup*

The Lidar measure the shaft's vibration of a motor installed in a complex system, called DyLab MVS 510, that can simulate a wide range of faulty condition such as bearings fault:

It is composed by an 0.37 Kw 50 Hz induction motor which drive a shaft with 4 bearings. The geometry of the bearings are (relevant to determine the fault frequency):

      i.   Ball diameter=7.95 [mm]
      ii. Pitch diameter =33.53 [mm]
      iii. Number of balls =8

The system is equipped with two normal bearings and two defective, in particular one has a inner race defect made with an 1 [mm] hole and the other bearing has a outer race defect made by a 1[mm] hole in the outer race. In order to simulate a fault in motor's bearings the defective bearings must be positioned in the slot 1 (see figure above), as close as possible to the motor; in slot 2 there is always healthy bearing.

The lidar will point straight to the shaft, approximately in point **A** (see figure above)**.** It is important that the lidar is mounted perpendicular to the shaft however any inclination can modify the measure. This happen because, the beat frequency, f_d is directly proportional to the shaft speed (ω) and is independent of any solid body motion of the shaft. If the plane of the laser beams is not perpendicular to the shaft axis, then f_d is also a function of $cos\ \theta$, where θ is the angle between the plane of the laser beams and the plane perpendicular to the axis of shaft rotation.

4) _testing phase_

The testing phase ill be divided into 2 part: at the beginning the system will run with only healthy bearing in order to check the correct alignment of the motor with the shaft and to determine the amplitude of the specific harmonics at normal condition using the lidar measurements. This can helps to check that the acquiring system is properly working. Then the motor will run with one of the defected bearing at time and the lidar will acquire the vibration signal of the shaft. A fault will be detected if the amplitude of an harmonic components is higher than the registered value at normal condition.

The load is a simulated with a magnetic motor attached to the main shaft through a reduction gearbox. This procedure will be repeated at different speed and with different load to confirm the ability to detect the fault in different conditions.

1.3. Novelty and Ambition:

A lidar is a non-contact sensor, that can be used to determine the speed of the motor, so to apply this technique the motor must not be modified. In fact, the actual technique requires to put a sensor on the motor or to the supplying cables, this could be very difficult if the motor is in hostile and uncomfortable places like for example on the wind turbine. The project wants to present how to determine the amplitude of displacement and speed of a motors shaft. Its mainly focused on properly setting the acquire system, Lidar, in order to communicate with a computer.

2. Impact

2.1. Potential for academic impact of the research project

The output of this project could be improved and it could raise new academic challenges. The processing phase of this project can be developed using a better noise filtration in order to obtain a more accurate fault detection. But also Determinate the continuous health status of a motor can helps to develop different type of predictive maintenance. For example, is possible to determine if some components inside of the motor are going to fault and schedule a maintenance before the broke ; this helps reducing drastically the downtime of a machine.

2.2. Potential for societal impact of the research project

The project's target audience is composed by all researcher whose need to implement different types of fault detection in motors, to improve their predictive maintenance scheme. But also, for who want to improve non-contact control of a motor, because it is allocated in a hostile environment for classic contact sensors.

2.3. Measurer for communication and exploitation

This work will be published in IEEE Industry Applications Magazine because can be useful for who wants to improve this project for example the data elaboration phase because this project is focused on the sensing part. But also, it can be improved introducing new technique to improve the ability to recognized the precise fault also with multiple fault..

3. Implementation

3.1. Project organisation and management

The project will be divided in different tasks as explained above: at the beginning we proceed with the setting of the Lidar and how to acquire its data. After the sensing part, we continue with the implementation of the code that must filter correctly the signal and then we execute the Fourier transform of the signal to determine the amplitude of each harmonic component. The system need to find in the signal spectrum the harmonics related to fault, for this reason we create a table of relevant frequency for each fault. Then the amplitude of each harmonics at normal condition will be registered so is possible to detect when a fault occur and which fault. This table will be validated experimentally. In the end, everything must be fused in a project and test the project in laboratory.

The workflow is described in the Gantt chart below:

| 2021 | Sep | Oct | Nov | 2021 |

Today

Set Lidar parameters and comunication with computer 9 Sep - 17 Oct

Data processing and filtering 17 Oct - 24 Oct

Experimental setup 21 Oct - 28 Oct

Data acquisition in normal and faulty condition 24 Oct - 10 Nov

BIBLIOGRAPHY

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[3] W. T. Thomson and M. Fenger, "Current signature analysis to detect induction motor faults," in *IEEE Industry Applications Magazine*, vol. 7, no. 4, pp. 26-34, July-Aug. 2001, doi: 10.1109/2943.930988.

[4] M. J. Devaney and L. Eren, "Detecting motor bearing faults," in IEEE Instrumentation & Measurement Magazine, vol. 7, no. 4, pp. 30-50, Dec. 2004, doi: 10.1109/MIM.2004.1383462.

[5] Paulo Antonio Delgado-Arredondo, Daniel Morinigo-Sotelo, Roque Alfredo Osornio-Rios, Juan Gabriel Avina-Cervantes, Horacio Rostro-Gonzalez, Rene de Jesus Romero-Troncoso, Methodology for fault detection in induction motors via sound and vibration signals

[6] P. D. McFadden and J. D. Smith, "Model for the vibration produced by multiple points defects in a rolling element bearing", J. Sound Vib., vol. 98, no. 2, pp. 263-273, Jan. 1985

[7] A. Garcia-Perez, R. d. J. Romero-Troncoso, E. Cabal-Yepez and R. A. Osornio-Rios, "The Application of High-Resolution Spectral Analysis for Identifying Multiple Combined Faults in Induction Motors," in IEEE Transactions on Industrial Electronics, vol. 58, no. 5, pp. 2002-2010, May 2011, doi: 10.1109/TIE.2010.2051398

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Continuous health status detection of a motor

1. **Excellence**
   1.1. **State of art, knowledge needs and projects objectives:**
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   $$f_{bearing} = f_0 \pm n_b f_{i,0}$$

   $$f_{i,0} = \frac{n}{2}(1-s)f_0\left\{1 \pm \frac{BD}{PD}\cos\beta\right\}$$

   Where n_b is the number of balls, PD is the bearing-pitch diameter, BD is the ball diameter, β is the contact angle of crack on races, and n is the positive integer, f_0 is the electrical supply

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where R is the number of rotor slots, $n_d = \pm 1$ is the eccentricity-order number, and $n_{\omega s} = 1,3,5,\ldots$, the stator MMF-harmonic rank, respectively.

Another way to determine the health status of a motor is the vibration analysis. It is based on the signal coming from accelerometer/vibrometers positioned on the crankshaft; 3-axis MEMS accelerometers are frequently used due to its ability to measure vibration at very low frequency, around 0Hz. Through the spectral analysis of the shaft-vibration is possible to determine the presence of fault inside the motor. The bearing fault related vibration frequencies are easily calculated with known bearing geometry and rotor speed [4]. The vibration frequencies show up also in the current spectrum as the modulation frequencies, therefore it is possible to provide continuous monitoring using motor current data, as in MCSA analysis, instead using crankshaft's vibration data.

Bearing faults such as outer race, inner race, ball defect, and train defect cause machine vibration and it results in air-gap eccentricity. These defects have vibration frequency components, f_v, that are characteristic of each defect type. The outer race defect frequency is:

$$f_{\text{oD}} = \frac{n}{2} f_{rm} \left(1 - \frac{\text{BD}}{\text{PD}} \cos \phi \right).$$

where f_{rm} is the rotor speed in revolutions per minute.
The inner race defect frequency is:

$$f_{\text{ID}} = \frac{n}{2} f_{rm} \left(1 + \frac{\text{BD}}{\text{PD}} \cos \phi \right).$$

Ball defective frequency is given by:

$$f_{\text{BD}} = \frac{\text{PD}}{2\text{BD}} f_{rm} \left(1 - \left(\frac{\text{BD}}{\text{PD}} \right)^2 \cos^2 \phi \right).$$

Cage defect frequency, caused by irregularity in the train, is given by:

$$f_{\text{CD}} = \frac{1}{2} f_{rm} \left(1 - \frac{\text{BD}}{\text{PD}} \cos \phi \right).$$

There is a relationship between the characteristic frequency of a fault in the current spectra and the vibration spectra. The characteristic current frequencies, f_{CF}, due to bearing characteristic vibration frequencies are calculate by

$$f_{\text{CF}} = |f_e \pm m f_v|.$$

where f_v is the vibration frequency components of the fault and f_e is the power system frequency.

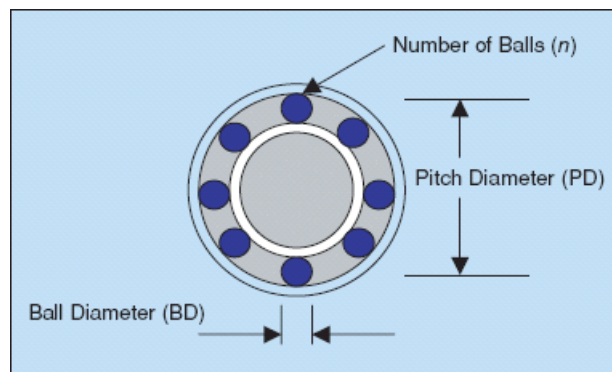The others parameters are relate to the geometry of ball bearing and is shown in the figure 1 below:

Figure 1 credits to [4]

All these techniques for fault diagnosis have advantages and disadvantages.

The MCSA technique has the advantages of being non-invasive, easy and cheap to implement, providing good results in fault diagnosis; however, under certain conditions its application is not sensitive enough because it has a low signal-to-noise ratio. In the other hand, vibration analysis has the advantage that its results are independent of the type of motor power supply, high reliability, low power consumption, low cost and yields good results, but its implementation requires using accelerometers as the basic sensors that must be placed near or on the motor, which sometimes is difficult to achieve.

To partially solve the problem of using only contact sensors, Paulo and Daniel [5] proposed to detect fault through sound and vibration signals; in fact the sound is a physical phenomenon that provides information about the behaviour of a system and can be used as a parameter for determining the condition thereof. The acoustic sound waves contain information about the health status of the machine because sound is produced by mechanical vibrations. The electric motor is not an exception, and the vibrations generated by defects in bearings, mechanical unbalances and broken rotor bars produce sounds with characteristic frequencies associated with each fault.

However the downside of sound signal analysis is its sensitivity to external noise , which should be avoided whenever possible; this limits enormously the application of this technique. The diagnosis through the analysis of acoustic sound signal is a first non-invasive method using non-contact sensor, a microphone in this case, to check the motor's status.

Vibrations are a key factor to determine the health of a motor. This project wants to determine the amplitude of the vibration of the shaft using a Lidar and analysing the presence of harmonics inside of the displacement is possible to retrace some known fault. McFadden [6] and M. J. Devaney [4] describe that every superficial defect of the mechanical components is related to a specific frequency that is proportional to the speed of the shaft, as reported before. But also other defects, specific for induction motor (most common type of motor in the industry), have typical harmonics in the spectrum.

1.2. Research question and hypothesis, theoretical approach and methodology

The development of the project is based on different research questions. Using a Lidar, it is necessary to determine the correct distance between the sensor and the shaft. Also, how it is possible to determine the amplitude of the displacement of the shaft while the motor is working. The presence of a load attached to the shaft can disturb the readings, if the load is unbalanced.

In a system with multiple-fault conditions present, such as broken rotor bars (BRBs), unbalance (UNB), and bearing defects (BDs), it is important to distinguish between the faulty conditions, [7]. When multiple faults exist, vibration and current are excited by several fault-related frequencies combined with each other, linearly or nonlinearly. Since multiple-fault situations may occur in the induction motor, a wrong conclusion may be drawn in the diagnosis based on the partial fault signature. Therefore, multiple-fault diagnosis is still a big challenge in the research of monitoring and maintenance of induction motors. This project considers that only one fault can occur in the motor for each run-time. Otherwise, as described in [7], the analysis of the vibration's spectrum become more complex; the main scope is to use a non-contact sensor to determine the health status, so the project is mainly focused on the acquisition part of the entire system and the signal processing.

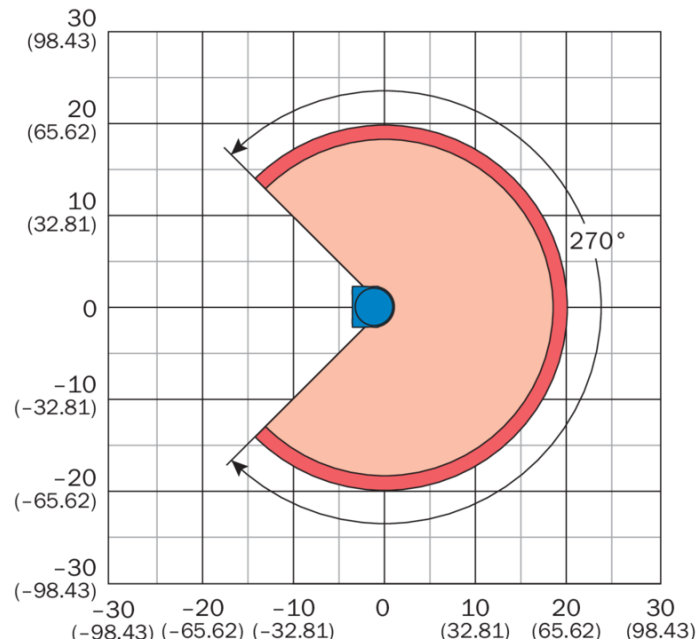The project workflow will be divide in different steps.

1)*Set appropriately the Lidar's parameters and the communication between the sensor and computer.*
For this project Sick 2D lidar is going to be used, in particular the LMS133, that it has an aperture angle of 270° horizontal with a frequency of 50/25 [Hz], and a very large range of detection (20 [m]), as default.

Figure 2: Lidar LMS133-10100

However this parameters need to be changed for the objective: reducing the aperture angle to few degrees because the aim is to monitor the distance of a specific point in the 2D plane with high accuracy, related to the shaft. Furthermore reducing the angle is possible to increase the frequency. The Lidar must be located near the shaft but not too much, following the SICK datasheet it has a minimum measuring distance of 0.5 [m].

The Lidar communicate with a computer, in this case a Jetson nano, through an ethernet cable thanks to the specific ROS package made by lidar's manufacturer; using ROS there is more flexibility in data manipulation so the distance data coming from Lidar can be process thanks to specific node created appropriately to the final scope. The message sent by the lidar is binary to reduce the traffic in the communication line, so a ROS node need to translate the binary code into a numerical number that can be easily processed.
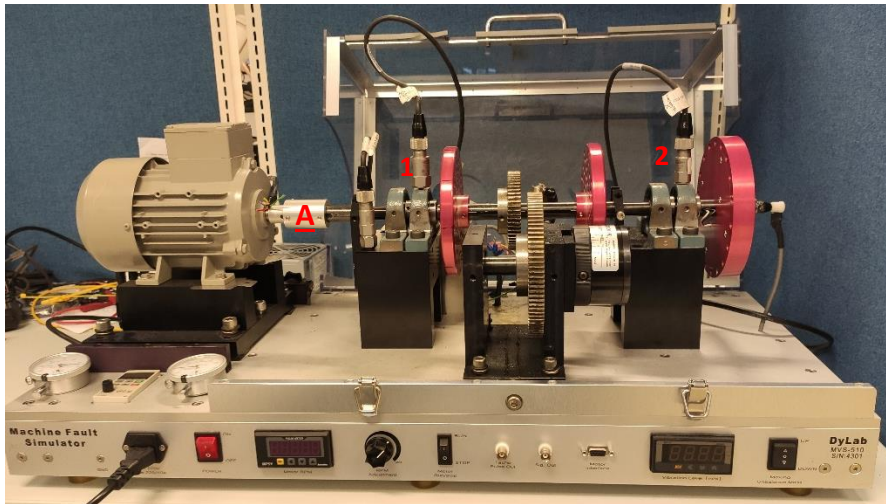
2) *Execute the fourier transform of the signal*
The signal will be noisy and can affect the output of Fourier transformation: one practical way to reduce noise is to apply retro-reflective tape to the target shaft to improve the measuring quality. The other way, more effective, is to filter the signal, the distance signal will be filtered using a band-pass filter to reduce white noise and the frequency range starts from the lowest detectable frequency possible which is related to the shaft's speed.
In order to execute the FFT of the signal, there will be used a python code that collect a specific amount of values coming from the Lidar and calculate the FFT. While it is doing that a new set of that will be collected so is possible to re-calcualted the FFT and updating the amplitude of harmonics in an apparent real time, because a fault could be detect if, at a specific frequency obtained using formulas described above, the harmonics has big amplitude in comparison to the amplitude at normal condition.

3)*Set the experimental setup*

The Lidar measure the shaft's vibration of a motor installed in a complex system, called DyLab MVS 510, that can simulate a wide range of faulty condition such as bearings fault:

It is composed by an 0.37 Kw 50 Hz induction motor which drive a shaft with 4 bearings. The geometry of the bearings are (relevant to determine the fault frequency):

        i.   Ball diameter=7.95 [mm]
        ii.   Pitch diameter =33.53 [mm]
        iii. Number of balls =8

The system is equipped with two normal bearings and two defective, in particular one has a inner race defect made with an 1 [mm] hole and the other bearing has a outer race defect made by a 1[mm] hole in the outer race. In order to simulate a fault in motor's bearings the defective bearings must be positioned in the slot 1 (see figure above), as close as possible to the motor; in slot 2 there is always healthy bearing.

The lidar will point straight to the shaft, approximately in point **A** (see figure above)**.** It is important that the lidar is mounted perpendicular to the shaft however any inclination can modify the measure. This happen because, the beat frequency, f_d is directly proportional to the shaft speed (ω) and is independent of any solid body motion of the shaft. If the plane of the laser beams is not perpendicular to the shaft axis, then f_d is also a function of $cos\ \theta$, where θ is the angle between the plane of the laser beams and the plane perpendicular to the axis of shaft rotation.

4) _testing phase_

The testing phase ill be divided into 2 part: at the beginning the system will run with only healthy bearing in order to check the correct alignment of the motor with the shaft and to determine the amplitude of the specific harmonics at normal condition using the lidar measurements. This can helps to check that the acquiring system is properly working. Then the motor will run with one of the defected bearing at time and the lidar will acquire the vibration signal of the shaft. A fault will be detected if the amplitude of an harmonic components is higher than the registered value at normal condition.

The load is a simulated with a magnetic motor attached to the main shaft through a reduction gearbox. This procedure will be repeated at different speed and with different load to confirm the ability to detect the fault in different conditions.

1.3. Novelty and Ambition:

A lidar is a non-contact sensor, that can be used to determine the speed of the motor, so to apply this technique the motor must not be modified. In fact, the actual technique requires to put a sensor on the motor or to the supplying cables, this could be very difficult if the motor is in hostile and uncomfortable places like for example on the wind turbine. The project wants to present how to determine the amplitude of displacement and speed of a motors shaft. Its mainly focused on properly setting the acquire system, Lidar, in order to communicate with a computer.

2. Impact

2.1. Potential for academic impact of the research project

The output of this project could be improved and it could raise new academic challenges. The processing phase of this project can be developed using a better noise filtration in order to obtain a more accurate fault detection. But also Determinate the continuous health status of a motor can helps to develop different type of predictive maintenance. For example, is possible to determine if some components inside of the motor are going to fault and schedule a maintenance before the broke ; this helps reducing drastically the downtime of a machine.

2.2. Potential for societal impact of the research project

The project's target audience is composed by all researcher whose need to implement different types of fault detection in motors, to improve their predictive maintenance scheme. But also, for who want to improve non-contact control of a motor, because it is allocated in a hostile environment for classic contact sensors.

2.3. Measurer for communication and exploitation

This work will be published in IEEE Industry Applications Magazine because can be useful for who wants to improve this project for example the data elaboration phase because this project is focused on the sensing part. But also, it can be improved introducing new technique to improve the ability to recognized the precise fault also with multiple fault..

3. Implementation

3.1. Project organisation and management

The project will be divided in different tasks as explained above: at the beginning we proceed with the setting of the Lidar and how to acquire its data. After the sensing part, we continue with the implementation of the code that must filter correctly the signal and then we execute the Fourier transform of the signal to determine the amplitude of each harmonic component. The system need to find in the signal spectrum the harmonics related to fault, for this reason we create a table of relevant frequency for each fault. Then the amplitude of each harmonics at normal condition will be registered so is possible to detect when a fault occur and which fault. This table will be validated experimentally. In the end, everything must be fused in a project and test the project in laboratory.

The workflow is described in the Gantt chart below:

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