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Development of vibration monitoring system for rotating machine models using fast fourier transform

Iip Muhlisin [a,1], *Fachri Agung* [b,2], *Riki Efendi* [a,b,3]

[a]*Department of Industrial Engineering, Faculty of Engineering, Universitas Pamulang, Jl. Surya Kencana No.1 Kota Tangerang Selatan 15417, Banten, Indonesia*

[b]*Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta, Jl. Cempaka Putih Tengah 27, Kota Tangerang Selatan 15419, Banten, Indonesia*

E-mail: [1]dosen01937@unpam.ac.id, [2]agung.fachri@unpam.ac.id, [3]riki.effendi@ftumj.ac.id

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ABSTRACT

The spinning cylinder engine is often damaged mechanically. Vibrations in spinning machinery cause damage. The reasons for vibration in rotating machines include imbalance, misalignment, and faulty parts or faults in machine components. This research attempts to offer a solution by using an analytical method and a vibration monitoring system. The system may help with the detection process, displaying vibrations in graphic form, determining the amplitude and peak of the vibration, and computing the vibration frequency. In this research, a prototype of a vibration monitoring device was created by completing the load cell component as a vibration sensor, Arduino Atmega 2560 for the control system, and applying fast fourier transform.

ABSTRAK

Sering kali terjadi kerusakan mekanis pada mesin silinder berputar. Kerusakan itu terjadi akibat dari getaran yang terjadi pada mesin-mesin berputar. Penyebab getaran pada mesin berputar antara lain disebabkan oleh beberapa hal diantaranya: ketidakseimbangan, tidak sejajar, dan bagian yang tidak sempurna atau cacat pada komponen mesin. Penelitian ini mencoba untuk memberikan solusi dengan cara pendekatan analitik menggunakan sistem pemantau getaran. Sistem tersebut bisa memberikan manfaat dalam proses deteksi, memvisualisasi getaran dalam bentuk grafis, menemukan magnitudo yang merupakan puncak getaran dan menghitung frekuensi getarnya. Pada penelitian ini dikembangkan prototipe alat pemantau getaran dengan melengkapi komponen Load cell sebagai sensor getar, arduino atmega 2560 untuk sistem kontrol, dan mengimplementasikan fast fourier transform.

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1. Introduction

The machine's condition can be monitored in various ways and methods, which helps make decisions for its maintenance. In the analysis of mechanical characteristics, the use of vibration signals to determine the maintenance of the machine's condition is carried out without disassembling or stopping the machine. Then the results can be used for further analysis in repairing the damage that has been caused. Periodic monitoring of the vibration spectrum will detect the state of engine changes that lead to damage. Such monitoring can prevent more severe damage [1].

Vibration monitoring on machines provides many benefits including, preventing engine breakdowns, improving product quality, economical production costs, and lower maintenance costs [2]. This analysis aims for machine maintenance and creates early detection, and the results will be beneficial for scheduling activities, efficiently reducing downtime and losses [3]. Industrial fault repair measures are less popular than time-based preventive and predictive maintenance. Vibration monitoring is a tool used as a requirement in predictive maintenance procedures to make decisions regarding machine maintenance. The vibration level will signal the machine's condition from minor to severe damage [4], and the results of the analysis can be used as input for standard operating procedures and good machine maintenance.

Machine failure can be predicted by knowing the nature and level of damage to machine defects and the results of machine vibration measurements and analysis from machine vibration monitoring carried out in real-time. Vibration can be caused by many components incorporated in the cylinder engine. The source of vibration will be difficult to find if using conventional methods. Vibration monitors can help determine the vibrational character and different frequencies of mechanical damage to different components. There is a link between damage to specific components and specific vibration characteristics to detect abnormal vibrations and frequencies early [5].

In this research trial, a series of engine operation tests were carried out at different speeds, variations of the engine without loading, and the engine using the load. It is intended to distinguish between a normal machine without a load and an abnormal machine, a loaded machine. An engine with a load indicates that the cylinder rotates unbalanced so that it is said to be abnormal. Research [12] builds a vibration monitoring model that uses an accelerator sensor as the primary vibration sensor, a DC motor, and an Arduino Atmega 8535 microcontroller that controls all systems. The research concludes that vibrations from machines in balance and unbalance conditions can be monitored, transmitted, and processed in real-time. The model of this monitoring tool used in the study is shown in Figure 1.

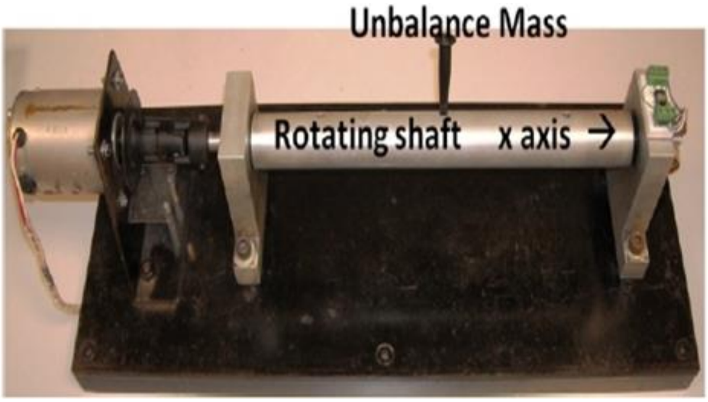


Figure 1. Vibration monitoring device in [12].

Several studies related to monitoring devices are [4, 9, 12]. This study is different from [9] and [12] because the object of research and the monitoring tools used are different. The monitoring device used in this study is shown in Figure 5. Research [12] used an accelerometer sensor as a vibration sensor, but this study used a load-cell as a vibration sensor. This study uses Arduino ATmega 2560 as an additional program aimed at improving the program's capabilities built in this study and developed a program by implementing fast fourier transform to perform better diagnostic visualization. The object studied by [9] is the vibration of the motor. Research [4] focuses on designing to build a prototype, and the resulting graph is a graph-based on theory, while this study produces graphs from trials.

2. Research Methodology

Theoretically, vibration is described as an object that regularly moves to make back and forth motion in equilibrium conditions. Vibration may alternatively be defined as a movement in the direction of the oscillation point, the source of which may be the mechanical movement of different types of machinery in operation [6]. Vibrations must have at least one parameter in order to be described and analyzed. There are three parameters to measure and analyze a vibration: the amplitude, frequency, and phase of the vibration. Amplitude is the highest point on the crest of a sinusoidal wave or the farthest deviation caused by vibration. Amplitude can provide information on the condition of an operating machine, whether the machine is in a healthy condition or not. If an engine experiences an ever-increasing vibration, the amplitude also increases.

Frequency is the number of vibrations in one second. The frequency of the vibration measurement can determine the type of disturbance. Frequency is also usually indicated in hertz (Hz). Phase is the final appearance of the vibration character that occurs in the engine during operating time. The displacement of the position from the reference starting point of a vibrating part is the definition of a vibrational phase. In analyzing and calculating vibrations, the vibration measurement of an object or medium must be described according to its character, as depicted in Figure 2.

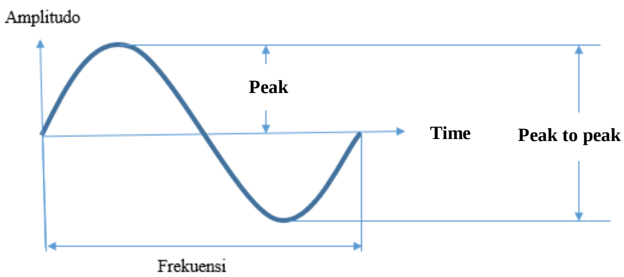


Figure 2. An illustration of vibration

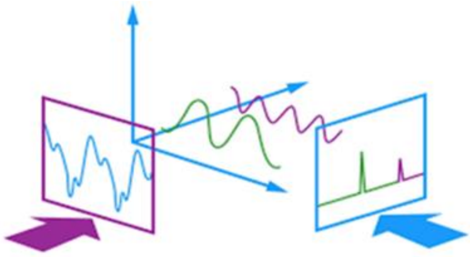


Figure 3. Signal change from time domain to frequency domain

Theoretically, there is a relationship between frequency and amplitude. The frequency is expressed inversely with the period. The period is the amount of time it takes in one cycle of movement. Vibration in a system occurs if there is a movement that is repeated with the same time interval. Here is the mathematical equation

$$\boldsymbol{F = \frac{1}{T}} \tag{1}$$

Where, F = Frequency; T = Period.

The dynamic motion system starts from time t = 0 as the initial state. If there is no external force, then the oscillatory motion of the system will move freely. One cycle of movement is propagation that starts from the initial position, then rises to a position at the top of the hill, then decreases back to a position parallel to the initial position, then moves to the lowest position, and finally returns to a position parallel to the initial position. This move will keep repeating itself. This movement is called periodic and harmonic vibrations. Theoretically, this movement has the following mathematical equation:

$$X = X_0 \sin(\omega t) \tag{2}$$

Where:

X	= position at time t	X_0	= maximum position
ω	= 2.π.f	f	= frequency (Hz)
t	= time		

Harmonic vibrations in an instrument or component occur when the number of vibrations that occur every second is constant. For example, there are guitars, heartbeats, and radio waves. Changes in the amplitude of vibrations on machines operating in a specific range are regular because it is influenced by various causes such as wear, changes in temperature, or changes in loading. However, suppose this change in amplitude exceeds a specific standard limit. In that case, the technician must take the following actions, including temporarily stopping the operation of the machine, scheduling corrective actions, or stopping the machine operation for a long time due to an increase in the very high amplitude of the machine vibration.

When the engine vibration level increases beyond the basic level limit, it indicates a fault problem. Through abnormal vibrations, it will be effortless to detect the beginning of a malfunction of a machine. The basic level limit of the machine is the state of the machine operating normally and stably. The limit is obtained through the data of machine vibration that has been measured and standard. This measured data can be compared with new data to detect changes in the state of the machine. The unstable condition of the machine looks different from its normal state [8].

Fast Fourier transform (FFT) was first introduced by [10]. The time-domain function converted to the frequency domain is the basis of the form of the signal analysis method using the fast Fourier transform [10], as shown in Figure 3. Frequency is the number of waves in one second, with the unit being Hertz (1/second). The signal in the analysis by FFT includes a signal with a sinusoidal component, which is then converted into the frequency domain. The development of a fast-computing algorithm for FFT was introduced by Gauss in his unpublished work in 1805, using a very similar method that Cooley and Tukey introduced in 1965, who invented the new FFT algorithm. The signal in frequency was the signal to be analyzed and processed in the FFT [10].

$$X(F) = \int_{-\infty}^{\infty} x(t) e^{-j2nkFt} dt \tag{3}$$

Where :

X (F) is a value from the calculation of the fourier transform.

x (t) is a signal value or function in the time domain, which involves the complex exponential equation of the signal with k = 0, ± 1, ± 2, ..., etc.

FFT can break a non-stationary signal into many small segments. The main disadvantage of FFT is the trade-off between time and frequency which causes the resolution to be deficient in the time domain but good in the frequency domain with large window widths. On the other hand, the resolution is good in the time domain but deficient in the frequency domain with a small window width [11]. In this study, the FFT algorithm can process data by transforming the vibration signal in the time domain into a vibration signal in the frequency domain. The vibration recording process is stored in digital form in the form of frequency-based vibration spectrum waves.

The design of the vibration monitoring device consists of a rotating cylindrical engine. The rotating shaft is measured for mechanical vibration by a loadcell, which sends an analog signal to the Arduino Atmega 2560 micro-controller. The analog signal is converted into a digital signal and sent to the computer. In the computer, a program has been made to process the vibration data so that the data can be made for the process of graphing the vibration spectrum. Figure 4 is a schematic of the hardware system built.

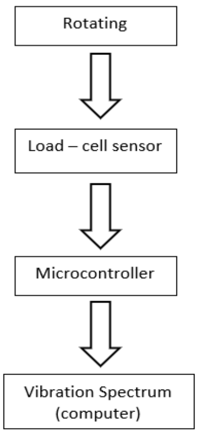


Figure 4. System block diagram

Figure 5. Prototype of vibration monitoring device

The prototype device for vibration testing is designed to control and regulate the rotational speed of the motor and adjust the load to create a measurable and controllable vibration. The components of this vibration monitoring device are a 1.5 KW AC motor as a shaft rotating power source, a Hitachi SJ 200 variable frequency drive (VFD) as a speed controller, an Arduino Atmega 2560 as a central controller, a flat motor transmitting belt, a rotor shaft as a vibration sensor tested, a Vishay Loadcell as a vibration detection sensor and a SUB-30 photosensor to calculate RPM. The prototype of the vibration monitoring device can be seen in Figure 5.

The rotor shaft will be driven by a HITACHI SJ 200 VFD and a 1.5 KW Motor, while the VFD functions to adjust the motor speed. Variations in speed will be carried out in this study. A photosensor and a disc encoder are used together to measure the rotor shaft speed. Figure 6 shows the algorithm in pseudocode, and Figure 7 shows a vibration monitoring wiring diagram.

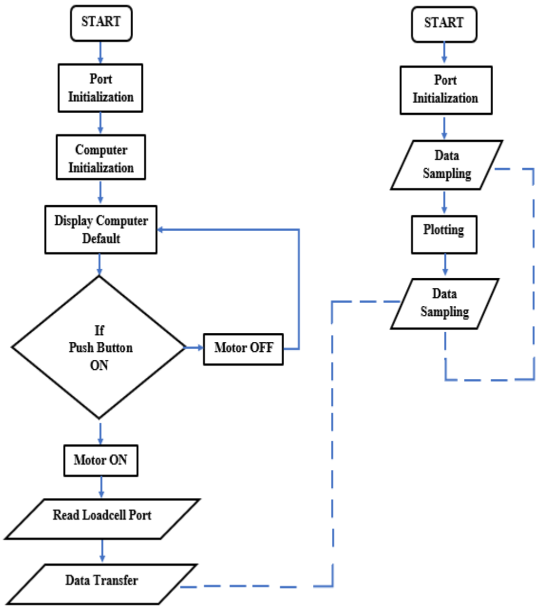


Figure 6. Algorithm in pseudocode

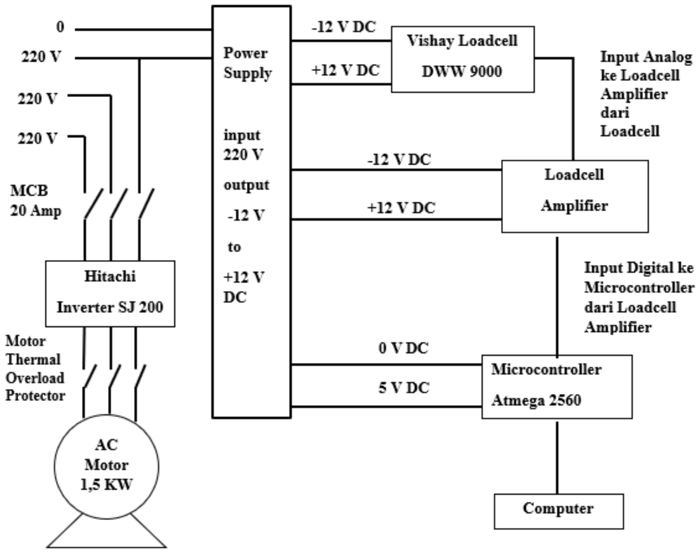


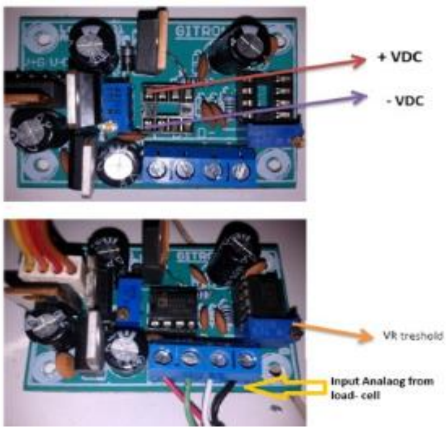
Figure 7. Wiring diagram

Machines that operate continuously at high speed will wear out and can cause damage. Some parts that are not balanced, looseness in the components, the relationship between one component and another must be checked. Vibrations caused by specific damage will create a unique frequency, then also create a unique Amplitude. This amplitude will indicate the extent of the damage to the machine. Therefore, the specific defects that occur in the engine unit can be mapped through vibration analysis. The Vishay shear beam load-cell shown in Figure 7 is used to measure the forces arising from the effect of the load on the shaft rotation. The load-cell in the device is capable of measuring from 0 to 250 kg.

Figure 8. ***Vishay single-beam load-cell***

Figure 9. Load-cell position in vibration monitoring device

The load-cell sensor is positioned at the end of the rotor illustrated in Figure 8, placed on a ball bearing, and positioned in the precise position. The Load-cell amplifier module, shown in Figure 9, functions to regulate the signal from the Load-cell at a voltage level between 0-5V so that it can be read by the microcontroller and the data is easier to process. The voltage generated from the load-cell is in micro-volts and cannot be measured with a voltmeter. As a result, a voltage amplifier is required to multiply the voltage by thousands or even hundreds of thousands of times before the voltage in volts can be detected using a voltmeter. The schematic of the load-cell amplifier is shown in Figure 10.



Gambar 10 . Load-cell amplifier

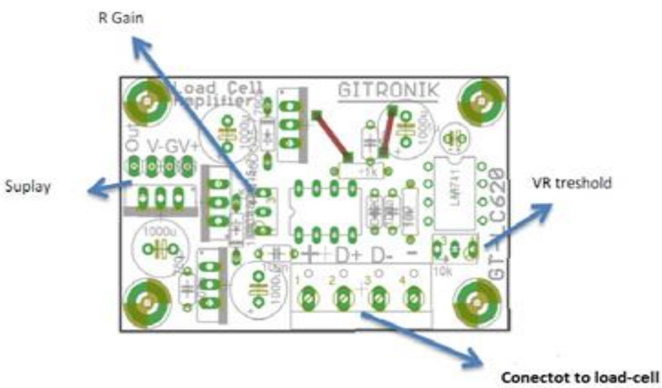


Figure 11. Load-cell amplifier schematic

Arduino is a device that can receive signals from the outside and can provide a response or feedback [13]. The incoming signal can be an analog signal or a digital signal. Sensors are usually connected to this device as a signal giver. The signal is analyzed and converted into a software system that enables the control of electromechanical devices such as motors and electro-pneumatics [14-15]. The vibration monitoring system in this experiment is controlled by the Atmega 2560 microcontroller shown in Figure 12. The Arduino Atmega 2560 is a microcontroller-based board having 54 digital input/output pins (14 of which can be used as PWM outputs), a hardware serial port (4 UARTs), 16 analog inputs, 16 MHz crystal oscillator, Mains connection, USB connection, reset button and ICSP header. The schematic of the Arduino Atmega 2560 microcontroller is shown in Figure 13. Its features provide everything needed to support the design of a vibration monitoring system.

Figure 12. Arduino Atmega 2560 microcontroller.

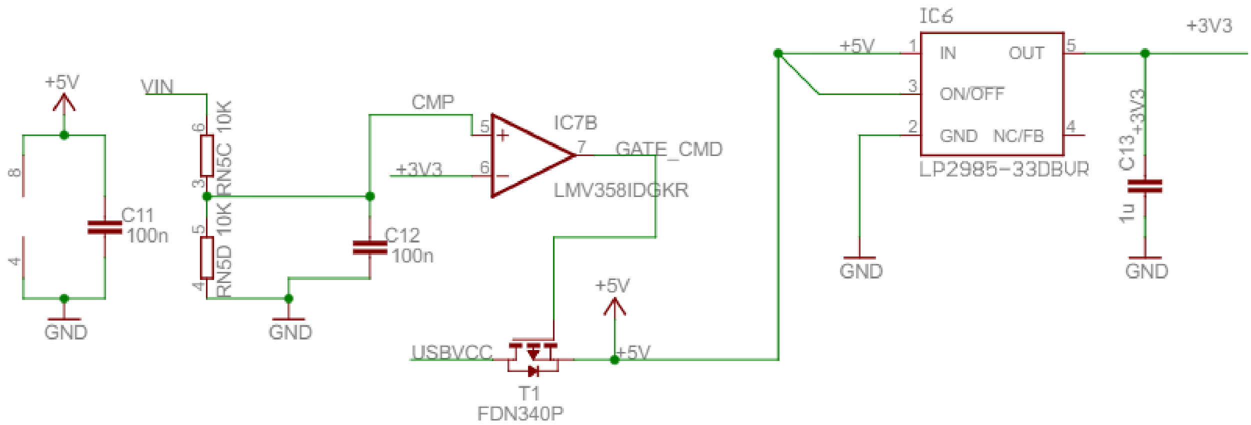


Figure 13. Schematic of Arduino Atmega 2560 microcontrollers.

The Yuema AC motor shown in Figure 14 is a prime mover with a power consumption specification of 1.5 Kilo Watt, 380 Volt, 50 Hz, 1400 Rpm. This motor is capable of driving the entire rotating unit in the device. The Yuema motor is controlled by a HITACHI SJ 200 VFD capable of regulating its speed and acceleration. The load shown in Figure 15 is used to generate vibrations during the test process. The load causes the rotation of the rotor shaft to become unbalanced because of the vibrations in this prototype change.

Figure 14. Yuema three-phase AC motor.

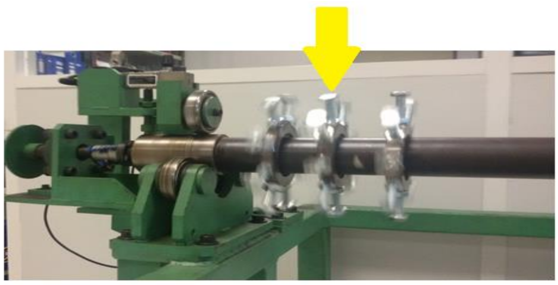


Figure 15. Load

The engine RPM sensor is generated by the BUD-30S photosensor shown in Figure 16. The photosensor was selected and implemented in the design of this system because it has several superior features, including high-speed response type, there is protection against excessive electric current shown in Figure 17, It has reverse polarity protection, has a selectable light/dark mode, and an IP65 waterproof structure (IEC specification).

Figure 16. Photosensor BUD - 30S

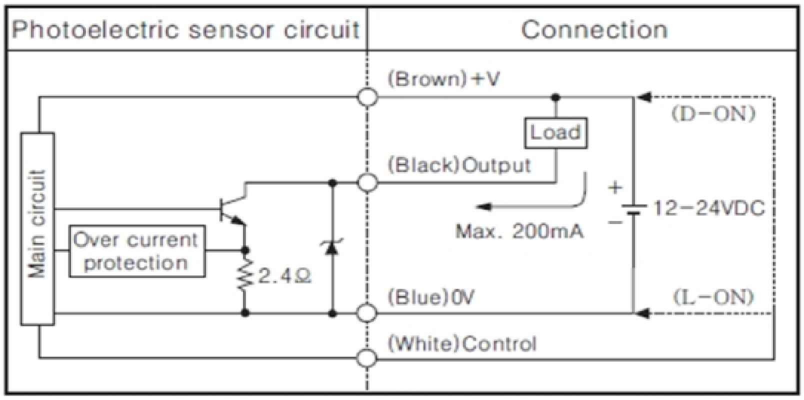
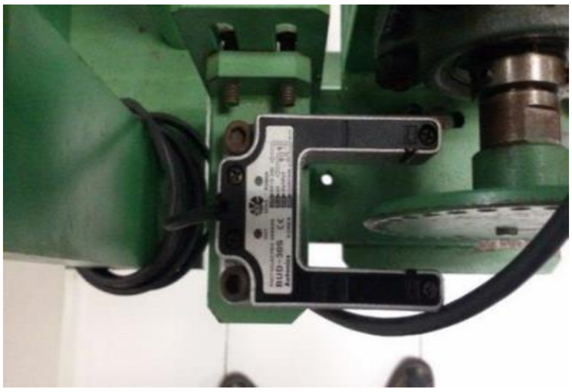


Figure 17. BUD – 30S control ouput diagram

Figure 18 shows the BUD-30S sensor mounted on the rotor shaft's edge and paired with the encoder disk. The encoder disk is used to cut off infrared light from the transmitter to the receiver. The disc encoder is equipped with one hole. When the disc rotates, the disc blocks the infrared. One-axis infrared with a disk hole will generate a signal. This signal will be sent as a digital input signal to the Arduino Atmega 2560. The Arduino Atmega 2560 will process the signal with the RPM program that has been created in the QT Creator software. The signal will be calculated in every rotation per minute in the program, and the result is RPM. The RPM value is displayed on the operating screen simultaneously, every 60 seconds, as shown in Figure 19.



Gambar 18. BUD – 30S photosensor dan encoder disk.

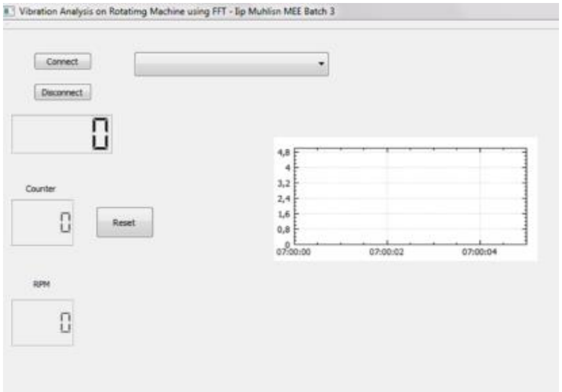


Figure 19. Operation screen.

3. Results and Discussion

This section contains an analysis of each graph plotted based on the frequency domain, which results from the FFT Algorithm. The graph shows the initial measurement, which is the reference point where the vibration monitoring device records a normal condition (balanced rotor shaft rotation condition) on the rotating machine without any loading on the machine. The first normal condition will be compared with the machine's condition that is given a load (unbalanced state). Increasing the rotational speed (RPM) was carried out in trials 3 and 4. The motor rotation speed was set at 100 RPM, and the engine was in average condition with no load in the first test. The results showed that the frequency value was 3.13 Hz, and the magnitude was 281, shown in Figure 20.

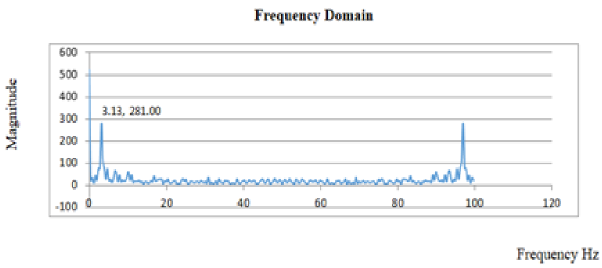


Figure 20. Vibration test analysis at 100 RPM without loading

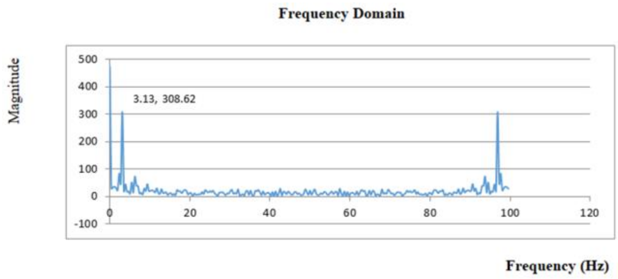


Figure 21. Analysis of vibration testing at 100 RPM with loading.

Figure 20 shows the magnitude 281 is a unique character in the engine condition without loading or under normal conditions. This result is a benchmark that will be compared with the subsequent trial results in the second experiment with a machine that is given a load. In the second trial, the motor rotation speed is set at the same speed as the first test, 100 RPM, and the engine is in an abnormal condition because a load is installed. The results of the results show a value in Figure 21.

Figure 21 shows the frequency value with the result remaining the same as in the first trial, which is 3.13 Hz, but the magnitude changes to 308.62. The results show the compatibility between theory and practice where the motor rotation with the same RPM speed will produce the same frequency. Meanwhile, the additional loading conditions will affect the magnitude of the vibration so that the frequency magnitude changes to be more significant than 281 in the first trial to 308.62 in the second trial. In the third trial, the author experimented by changing the motor rotation speed to be three times faster than experiments 1 and 2, which was 300 RPM, and the engine was in average condition without load. The results are shown in Figure 22.

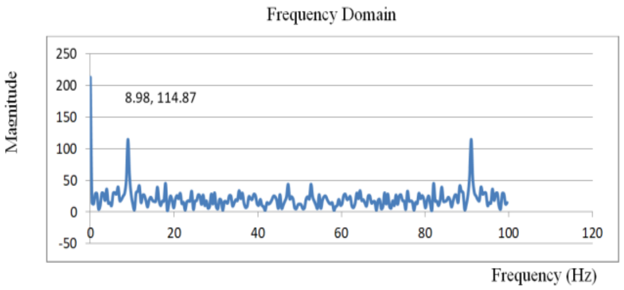


Figure 22. Vibration test analysis at 300 RPM without loading.

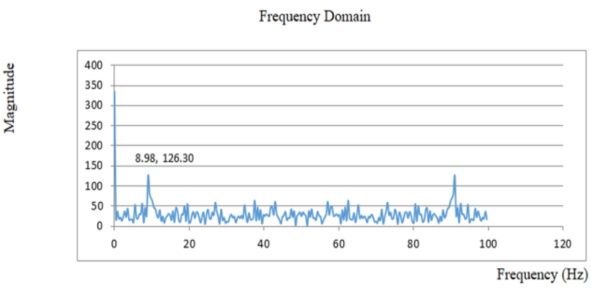


Figure 23. Vibration test analysis at 300 RPM with loading.

Figure 22 shows the results of the third experiment, which resulted in an increased frequency value from trials 1 and 2, namely from 3.13 Hz to 8.98 Hz. The results show that the rotational speed affects the frequency. The quicker the spin, the more frequent the vibration frequency. Meanwhile, the frequency magnitude decreases when comparing it with trials 1 and 2, changing from 281 and 308.62 to 114.87. These results indicate that the faster the rotation, the smaller the magnitude of the frequency produced. In the fourth trial, the motor rotation speed is set at the same speed as in the third trial, 300 RPM. The results show the engine is in an abnormal condition because a load is installed. The results are shown in Figure 23. Figure 23 shows the results of the Frequency value, which remains the same as in the third trial, which is 8.98 Hz. The results show the correspondence between theory and practice where the rotation of the motor with the same RPM speed will produce the same frequency. Meanwhile, increased load in the fourth trial impacts frequency magnitude, which rises from 114.3 to 126.30 compared to the third trial.

Table 1. Frequency spectrum

Data from trial results 1 to 4				
RPM	Normal without loading		With loading	
	Frequency (Hz)	Magnitude	Frequency (Hz)	Magnitude
100	3,13	281	3,13	308,62
300	8,98	114,87	8,98	126,3

Table 1 contains a summary of the vibration test analysis graph. Table 1 categorizes the research according to their RPM, frequency value, and frequency magnitude. Table 1 demonstrates that the same RPM group generates the same frequency, that increasing RPM produces a higher frequency, and that the group with an increased frequency magnitude load is greater than the usual group without loading.

4. Conclusions

As indicated in Table 1, the frequency spectrum may be used to identify speed and load variation situations. FFT-based frequency-based analysis has proved to help monitor the features of the engine vibration signal since it provides a better visual representation than traditional techniques and can help observe the frequency and magnitude values. Frequency is a distinct characteristic that may be compared to various circumstances, such as machines in normal conditions without load, machines in abnormal conditions (through loading), and machines with varying RPM rotating rates.

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References

[1] Susilo, D. D. (2009). Pemantauan kondisi mesin berdasarkan sinyal getaran. *Mekanika*, vol. 8, no. 1, pp. 130-134.

[2] Pedotti, L. A. D. S., Zago, R. M., & Fruett, F. (2017). Fault diagnostics in rotary machines through spectral vibration analysis using low-cost MEMS devices. *IEEE Instrumentation & Measurement Magazine*, vol. 20, no. 6, pp. 39-44.

[3] Zarkasyi, M. (2014). Analisis sistem pemeliharaan dengan konsep lean maintenance pada industri otomotif (Studi kasus PT TVS). *Doctoral Dissertation*. Bekasi: Universitas Presiden.

[4] Muhlisin, I. (2020). Rancang bangun prototype alat deteksi getaran. *TEKNOLOGI: Jurnal Ilmiah dan Teknologi*, vol. 2, no. 1, pp. 1-6.

[5] Setyawan, D. B., & Sufiyanto, S. (2013). Metode vibration analysis dalam aplikasi perawatan mesin. *Jurnal Teknik Mesin Transmisi*, vol. 9, no. 2, pp. 921-930.

[6] Hermansyah, H., Gunawan, G., & Herayanti, L. (2017). Pengaruh penggunaan laboratorium virtual terhadap penguasaan konsep dan kemampuan berpikir kreatif siswa pada materi getaran dan gelombang. *Jurnal Pendidikan Fisika dan Teknologi*, vol. 1, no. 2, pp. 97-102.

[7] Rahmad, F. (2020). Karakteristik getaran pada piringan tunggal akibat pemberian massa pada variasi jari-jari piringan tunggal. *Doctoral Dissertation*. Medan: Universitas Muhammadiyah Sumatera Utara.

[8] Yan, X., & Jia, M. (2019). Intelligent fault diagnosis of rotating machinery using improved multiscale dispersion entropy and mRMR feature selection. *Knowledge-Based Systems*, vol. 163, pp. 450-471.

[9] Musthofa, A., Asfani, D. A., Negara, I. M. Y., Fahmi, D., & Priatama, N. (2016). Vibration analysis for the classification of damage motor PT Petrokimia Gresik using fast fourier transform and neural network. *2016 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, *IEEE Conference Proceedings*, pp. 381-386.

[10] Gabor, D. (1946). Theory of communication. Part 1: The analysis of information. *Journal of the Institution of Electrical Engineers-Part III: Radio and Communication Engineering*, vol. 93, no. 26, pp. 429-441.

[11] Lakis, A. A. (2007). Rotating machinery fault diagnosis using time-frequency methods. *The 7th WSEAS International Conference on Electric Power Systems, High Voltages, Electric Machines, Citeseerx*, pp. 139-144.

[12] Djajadi, A., Azavi, A., Rusyadi, R., & Sinaga, E. (2012). Monitoring vibration of a model of rotating machine. *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, vol. 2, no. 1, pp. 51-56.

[13] Kadir, A. (2017). *Pemrograman Arduino dan Processing*. Jakarta: Elex Media Komputindo.

[14] Rohman, A. Z. (2015). Rancang bangun alat ukur getaran mesin berbasis arduino. *Doctoral Dissertation*. Semarang: Universitas Negeri Semarang.

[15] Patil, S. S., & Gaikwad, J. A. (2013, July). Vibration analysis of electrical rotating machines using FFT: A method of predictive maintenance. *2013 Fourth International Conference on Computing, Communications and Networking Technologies* (*ICCCNT*), *IEEE Conference Proceedings*, pp. 1-6.