European Journal of Technique

journal homepage: https://dergipark.org.tr/en/pub/ejt

Vol.13, No.1, 2023

Investigation of Static and Dynamic Analysis of Asynchronous Motors in the Cement Industry

Hayrullah Cagtay ALKAYA[1*] and, Sertac GORGULU[2]

[1*] Burdur Mehmet Akif Ersoy University, The Graduate School of Natural and Applied Sciences, 2130127009, Burdur, Turkey. (e-mail: alkayacagtay@gmail.com).
[2] Burdur Mehmet Akif Ersoy University, Dep. of Electrical - Electronics Eng., Burdur, Turkey. (e-mail: sgorgulu@mehmetakif.edu.tr).

ARTICLE INFO

Received: Dec., 26. 2022
Revised: Jan., 12. 2023
Accepted: Jan., 15. 2023

Keywords:
Predictive maintenance
Asynchronous motor
Dynamic analysis
Static analysis
Vibration
Cement

Corresponding author: *H.Çağtay ALKAYA*

ISSN: *2536-5010* | e-ISSN: *2536-5134*

DOI: https://doi.org/10.36222/ejt.1223666

ABSTRACT

Today, with the developing technology, it is important to establish facilities suitable for industry 4.0 in order to reduce CO_2 emissions in factories, ensure efficiency, and automatically monitor the systems. Cement Factories are at the forefront of energy-intensive sectors. The cement industry is constantly focused on production, high energy demand and unforeseen failures lead to high-cost loss and systemic crises with the decrease in production/sales targets. Predictive maintenance, which is one of the maintenance methods, is aimed to solve the problems by determining the failure sources that may occur economically by examining and analyzing the physical parameters such as vibration, temperature, frequency changes, amperes, and spectra of the asynchronous motors in the field in trend data. In this study, dynamic and static analysis of large power asynchronous motors with a stator voltage of 6300V in cement plants are analyzed with the help of advanced measuring instruments. As a result of the analyses, a general evaluation study was carried out on the actions to be implemented in the maintenance plan by identifying the types of failures that may occur in advance.

1. INTRODUCTION

As the number of industries increases with the developing technology in Turkiye and the world, energy demands also increase [1]. Each increase brings with it the proliferation and development of energy production facilities together with excess consumption. In Turkiye, cement industrial facilities are among the most energy-intensive sectors.

In the cement industry, various maintenance methods have been developed to operate the process according to the standards, to ensure the continuity of production, to eliminate the risks of occupational accidents, and to prevent energy losses [2]. The machine equipment used in this industry has an important place in the process as they operate under heavy drive and load, and predictive maintenance, which is one of the maintenance methods, plays an important role since the failure of the equipment will negatively affect production [3].

The machines operated in the units within the enterprise should be monitored and reported in certain plans and periods, and as a result of the analyses, when an undesirable situation is encountered, the machine equipment and the unit should be taken into the stop plan and maintenance work should be started [4]. In case of malfunction, the operation of the equipment will lead to weakening in the process, low quality of the material produced, unplanned stoppage of the unit, and consequently cost loss.

Approximately half of the electrical energy obtained from power generation facilities in Turkiye is consumed in such industrial facilities. Approximately 70% of the electrical energy used in these facilities is consumed by electric motors [5, 6].

Since asynchronous motors are essential in the cement industry and use the majority of electrical energy, electrical and mechanical maintenance controls must be carried out for asynchronous motors to operate efficiently and to avoid losses in process and production. These controls are carried out by condition monitoring and analysis methods [7].

With electrical condition monitoring and analysis methods, unbalanced phase losses, overload, short circuits between phases, short circuit and open windings, tilted rotor faults, broken rotor bars, and insulation faults can be detected [8].

Mechanical condition monitoring and analysis methods can detect faults such as unbalance, bearing failure, mechanical looseness, gear failure, coupling misalignment, and axis disturbance [9].

Predictive maintenance can be characterized as a set of efforts to compare, analyze and interpret engineering limits by measuring and examining trend data such as vibration, temperature, pressure, voltage, increases in the amperes drawn by the motors of the equipment in active operation, and to provide the most economical and fastest solution to the problems that may become malfunctioning [10, 11].

There are some criteria for data interpretation during field studies and analysis. Engineering activities and limit definitions must be done correctly. Although the physical parameters of the measuring equipment are known, the working environment and process data must also be well-analyzed [12].

Establishing the necessary infrastructure for the efficient implementation and operation of predictive maintenance activities is important for the continuity of production and the efficiency of the process [13]. The benefits of this maintenance activity are;

- Minimizing costs in maintenance and repair activities
- Maximum product quality and process efficiency
- Reduced downtime of equipment
- Ensuring energy efficiency by complying with the work plan of the maintained unit
- Reducing breakdowns and keeping equipment ready for operation
- Increasing the reliability levels of equipment
- Optimization of spare parts by timely estimation of parts planned to be replaced
- The most efficient use of the labor force
- Reducing and eliminating OHS risks
- Achieving maximum efficiency from the capital spent for the operation by ensuring the efficiency of the equipment.

To determine and evaluate the instant operating conditions of the equipment in industrial facilities and to carry out maintenance activities within the plans, fault detection with vibration analysis, fault detection with thermal camera measurements, damage detection with oil analysis, damage detection with visual analysis, damage detection with sound analysis are transferred to the computer environment with the processing of the signals after the data collection system operations. Following these studies, the actions to be taken are determined [14].

Predictive maintenance appears as a philosophy of care. Evaluating the analyses in a computer environment and turning the studies carried out in the field into practice and receiving the returns in terms of efficiency-cost are studies that all units in the industry should contribute. Predictive maintenance work should be seen as teamwork rather than being applied alone [2, 14].

In the global and national cement industry, there are asynchronous motors, compressed air compressors, multistage gearboxes, low and high-capacity fans, and material handling equipment operating with low and high voltage. Due to the high installation and operating costs of this equipment, the system must be used until the end of its useful life [2, 14]. One of the key points of increasing equipment efficiency is to monitor and analyze the system data before failures occur and to eliminate problems by root-cause analysis. During the evaluation of analyses, it will not be sufficient to act on a single data point. Clearer and more positive results are obtained if process data is analyzed as well as multiple data and evaluated by considering environmental and ambient conditions [15].

Within the scope of this study, the dynamic analysis of the asynchronous motor with a stator voltage of 6300V operating under heavy load and drive in the Crusher-1 unit and the static analysis of the asynchronous motor of the Cement Mill-3 unit were examined and the areas for improvement were identified and the points where maintenance is required were determined.

2. MATERIAL AND METHODS

In this study, static and dynamic tests and analysis of the main drive motors and system fans with a stator voltage of 6300V belonging to the units used in a large cement factory industrial plant will be carried out. The components of the measurement operation of these motors are the asynchronous motor, the data acquisition system, and special equipment for data processing. Pruftechnik Vibscanner 2 model portable data collector vibration device, SKF Static Motor Analyzer Meger-Baker device, and thermal camera equipment will be used.

2.1. Characteristics of the Equipment to be used in Dynamic Analysis

In the field study of vibration measurements in dynamic plants, a device with universal software that facilitates easier, more powerful condition monitoring by analyzing vibration signals and process variables by simultaneously measuring overall values, spectra, and time signals in 3 axes, depending on filter settings, with 3-channel route-free measurements with a sampling rate of up to 131 kHz per channel, was used as a data collector. The label data of the asynchronous motors to be measured will be defined for the device to be used and the work will be started after the measurement points are determined. Once collected, the data will be computerized for signal processing [16].

Figure 1. Vibration FFT Analyzer [16]

2.2. Features of Equipment to be used in Static Analysis

In static tests, insulation resistance, insulation conditions, and short circuit analysis of the windings of a motor are required to maximize the efficiency of asynchronous motors. In our field applications, a special device with easy portability, maximum test voltage between 4–40 kV, record storage capacity of approximately 400 coils, source current maximum of 600 mA, overcurrent error 1.2 mA, ease of data transfer by USB and universal software were used. After the asynchronous motors to be measured are de-energized and safety applications are completed, the operation will be run following that the

EUROPEAN JOURNAL OF TECHNIQUE, Vol.13, No.1, 2023

connections are made on the motor supply terminals. Once the data is collected, it will be transferred to a computer for signal processing [17].

Figure 2. Static Motor Analyzer SKF Baker DX Series [17]

3. RESULTS AND DISCUSSION

3.1. Investigation of Vibration Analysis of Asynchronous Motors with Dynamic Testing

The crusher-1 main drive motor is an important piece of equipment belonging to the unit that crushes the raw materials coming to the factory. In order to operate the motor efficiently, electrical and mechanical maintenance work must be carried out in certain periods. The shape of the motor, from which the vibration data is collected, is horizontal and connected to the steel frame with foot bolts. The front and rear bearings of the induction motor consist of grease-lubricated ball bearings. It is connected to the system it drives by a belt-pulley system. Shim plates are evenly distributed on the motor legs for vibration control. The tag values of the motor are given in Table I.

TABLE I.
CRUSHER-1 MOTOR TAG INFORMATION

Tag Information	Tag Values
Brand	WSW
Type	Orr34635-6
Power	450 kW
Handover	988 rpm
Stator Voltage	6300 V

Vibration measurement values of the main drive motor are given in Table II.

TABLE II.
CRUSHER-1 MAIN DRIVE MOTOR VIBRATION MEASUREMENT VALUES

	Vibration value mm/s	
	Motor	Load
DE Horizontal	5.441	1.360
DE Vertical	2.605	2.333
DE Axial	3.835	1.456
NDE Horizontal	6.116	
NDE Vertical	4.827	
NDE Axial	3.727	

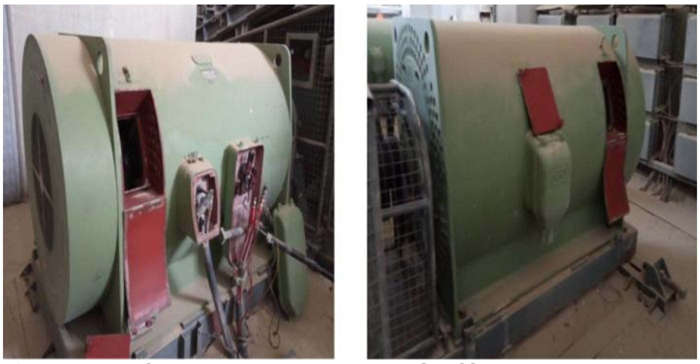

Figure 3. Crusher-1 Main Drive Motor General Field View

Figure 4. Crusher-1 Motor DE Horizontal Vibration Analysis

DE Horizontal measurement shows a dominant signal corresponding to 1X layer of the RPM. This signal can be characterized as unbalanced. Since the motor is integrated into the load with a belt-pulley system, the belt-pulley settings should be checked and recalibrated. Although it is observed as unbalanced in the 1X layer, other factors should also be examined. In the literature, the change in vibration values of 1X times over time is referred to as “light rotor rubbing”. For this reason, it would be useful to measure and check the bearing cover clearances. Other reasons to suspect friction failure are due to DE vertical and DE axial measurements. Light rubbing can be triggered by geometric misalignment problems (shaft misalignment due to thermal expansion), and specific load and temperature values.

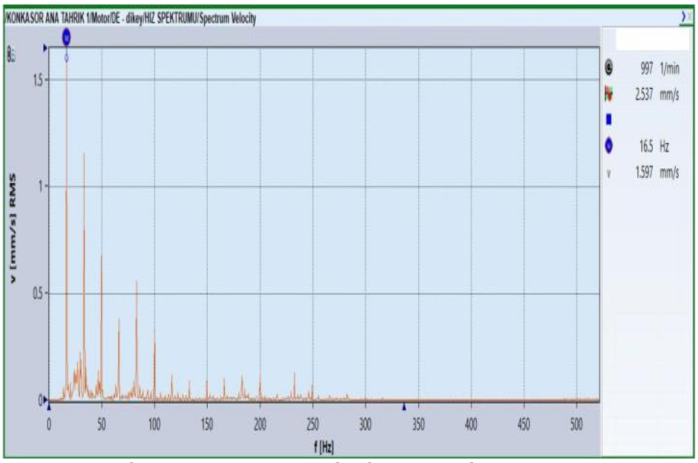

Figure 5. Crusher-1 Motor DE Vertical Vibration Analysis

 ISSN 2536-5010 | **e-ISSN** 2536-5134 https://dergipark.org.tr/en/pub/ejt

DE vertical measurement shows high signals predominantly at the 1X layer and as a side factor at the 2X, and 3X layers. Bearing cover clearance needs to be checked and also balancing adjustments need to be made.

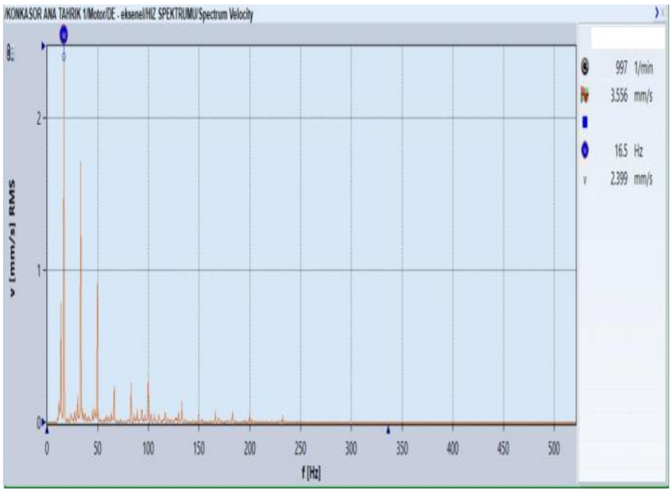

Figure 6. Crusher-1 Motor DE Axial Vibration Analysis

DE axial measurement shows a graph of the speed in multiples of 1X, 2X, and 3X. The signals in these layers occur when the motor shaft and the rotor shaft coincide at a certain distance. Angular misalignment causes high vibration in the axial direction and a 180-degree phase difference between the two shafts. It is necessary to check the gap between the bearing and the cover during maintenance. Since it is connected to the system with a belt pulley, it will be beneficial for process and motor efficiency to readjust its adjustment during maintenance.

3.1.1. Crusher-1 Main Drive Motor Analysis Results and Suggestions

During the vibration test performed on the Crusher-1 main drive motor, the vibration values of the motor are above the standards. It is observed that the dominant signals seen at the 1X layer are due to unbalance, with angular misalignment and slight rotor friction as side factors. When the vibration graphs are examined, it is seen that these signals are caused from the motor. The motor is connected to the load by a belt-pulley system. It is necessary to check the adjustment of the belt-pulley system to which it is connected with the load and to make a new adjustment. In addition, the graphs of the measured vibration values show harmonics in the bearing carrier covers, which means a gap.

3.2. Static Test Analysis Review of Asynchronous Motors

The main drive motor of the Cement Mill-3 is one of the most important main pieces of equipment of the unit where the grinding of cement is carried out. The shape of the motor is horizontal and connected to the steel frame with foot bolts. The front and rear bearings of the asynchronous motor consist of grease-lubricated ball bearings. The gearbox it drives is geared and connected by coupling. Shim plates are evenly distributed on the motor feet. The air filters are clean. The tag values of the motor are given in Table III.

TABLE III.
CEMENT MILL-3 MOTOR TAG INFORMATION

Tag Information	Tag Values
Brand	SIEMENS
Type	1RS-1802-5HA-90-Z
Power	1600 kW
Handover	493 rpm
Stator Voltage	6300 V

Figure 7. Cement Mill-3 Main Drive Motor General Field View

TABLE IV.
STATOR RESISTANCE, INDUCTANCE, AND CAPACITANCE MEASUREMENT VALUES

Stator Resistance	Lead 1-2	Lead 2-3	Lead 3-1	Unbalance [%]	Average
DC Resistance [mΩ]	264.3624	255.5788	264.3221	2.2	261.4211
Temp Corrected R [mΩ]	286.9501	277.3996	268.8416		283.7304
Inductance					
Frequency [Hz]	50.0	50.0	50.0		
Impedance [mΩ]	24.730	24.676	24.639	0.2	24.682
Impedance Ang [°]	45.3	45.3	45.3	0.0	45.3
Inductance [mH]	55.945	55.849	55.741	0.2	55.845
Dissipation Factor	0.990	0.989	0.990		
Capacitance					
Frequency [Hz]	4000.0				
Capacitance [nF]	4600.5				
Dissipation Factor	22.747				
Quality Factor	0.044				
Temperature	32.0 [°F]				

 ISSN 2536-5010 | **e-ISSN** 2536-5134 https://dergipark.org.tr/en/pub/ejt

Table IV shows that the DC resistance levels and temperature resistances between the phases of the stator are at a good level with an average of 261.4211 mΩ. The impedances between the phases are measured as balanced and the average is 24.6828 mΩ.

TABLE V.
CEMENT MILL-3 MAIN DRIVE MOTOR ROTOR HIPOT MEASUREMENT VALUES

Rotor Insulation Resistance (IR) Result	
Voltage [V]	1090
I [μA]	0.899
IR [MΩ]	1212
HiPot Result	
Voltage [V]	1550
I [μA]	0.976
IR [MΩ]	1588

In Table V, the rotor HiPot measurement values are given. As seen in Table V, the insulation resistance (IR) is measured at 1212 MΩ and 1588 MΩ at 1090 V and 1550 V measurements on the rotor. Insulation levels are measured as well. Fig. 8 shows the DC test results of the rotor. Where; IR is insulation resistance.

TABLE VI.
CEMENT MILL-3 MAIN DRIVE MOTOR STATOR HIPOT MEASUREMENT VALUES

Stator Insulation Resistance (IR) Result	
Voltage [V]	5120
I [μA]	0.506
IR [MΩ]	10119
HiPot Result	
Voltage [V]	6310
I [μA]	0.473
IR [MΩ]	13340

In Table VI, the stator HiPot measurement values are given. In Table VI, the insulation resistance (IR) on the stator was measured as 10119 MΩ and 13340 MΩ at 5120 V and 6310 V. Insulation is measured at a good level. Fig. 9 shows the DC test results of the stator. Where; IR is insulation resistance.

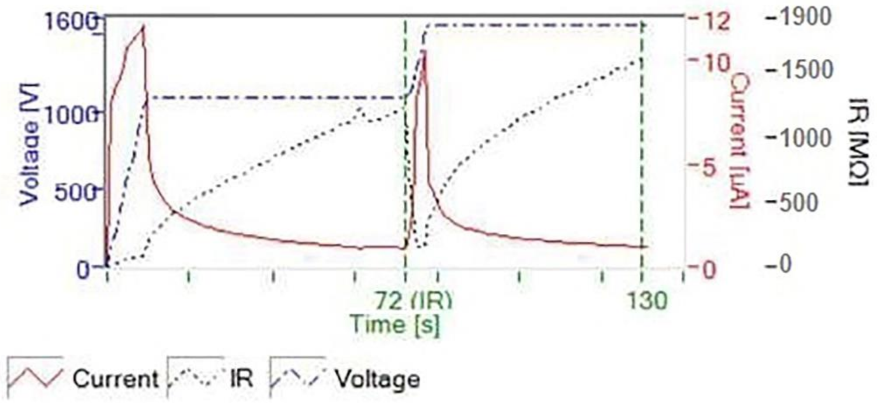

Figure 8. Rotor DC Test Results

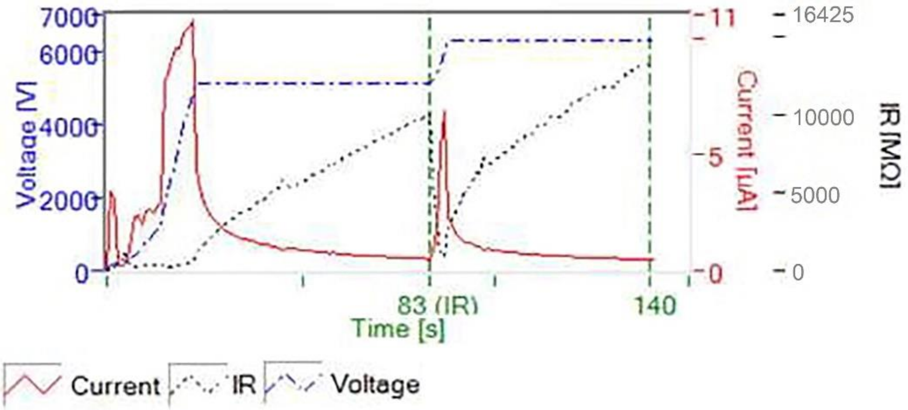

Figure 9. Stator DC Test Results

TABLE VII.
CEMENT MILL-3 MAIN DRIVE MOTOR ROTOR SURGE TEST MEASUREMENT VALUES

Lead	Peak Voltage [V]	Number of Pulses	PP EAR Status	Max. PP EAR[%]
1	1540	9	PASS	3
2	1540	3	PASS	2
3	1540	5	PASS	3

In Table VII, the rotor surge test measurement values are given. Fig. 10 shows the surge test graphs of the rotor. In Fig. 10, the number of pulses at the peak voltage of 1540 V applied to the rotor can be seen intact in the surge waveform.

In Table VIII, the stator surge test measurement values are given. Fig. 11 shows the surge test graphs of the stator. In Fig. 11, at a peak voltage of 6260 V between phases applied to the stator, the ripple waveform between phases is observed normally.

TABLE VIII.
CEMENT MILL-3 MAIN DRIVE MOTOR STATOR SURGE TEST MEASUREMENT VALUES

Lead	Peak Voltage [V]	Number of Pulses	PP EAR Status	Max. PP EAR[%]
1-2	6260	10	PASS	0
2-3	6260	5	PASS	2
3-1	6260	7	PASS	2

3.2.1 Cement Mill-3 Main Drive Motor Analysis Results and Suggestions

After static tests and visual inspections of the main drive motor of Cement Mill-3, negative conditions were not found. There are no abrasion, ovality, and arc marks on the ring surface. The engine coals were pressed against the bracelet in a normal condition and there was no tooth loss. The distances between the pressures of the portables are measured at the correct level. The insulation resistance (IR value) and vibration values of the motor are in accordance with ISO standards.

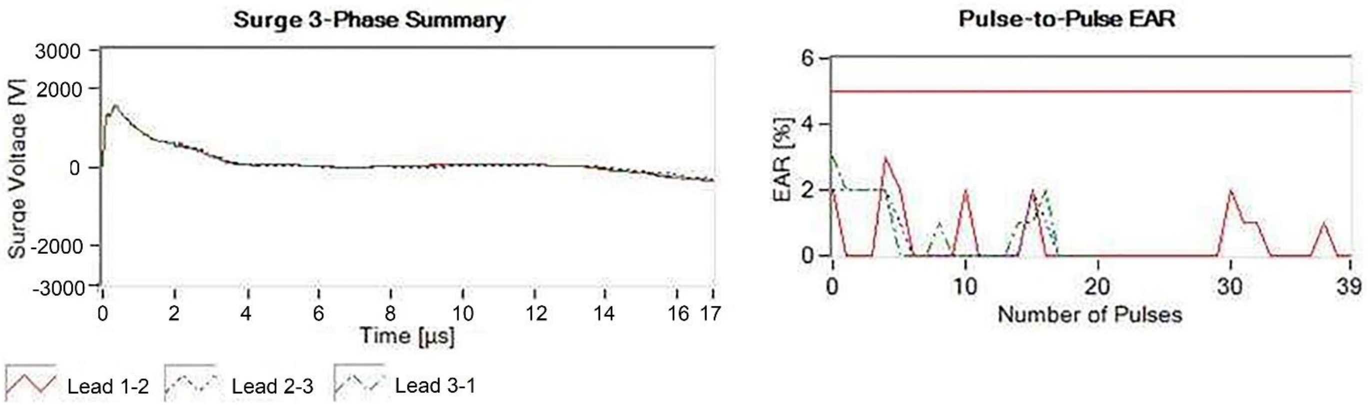

Figure 10. Rotor Surge Test Graphics

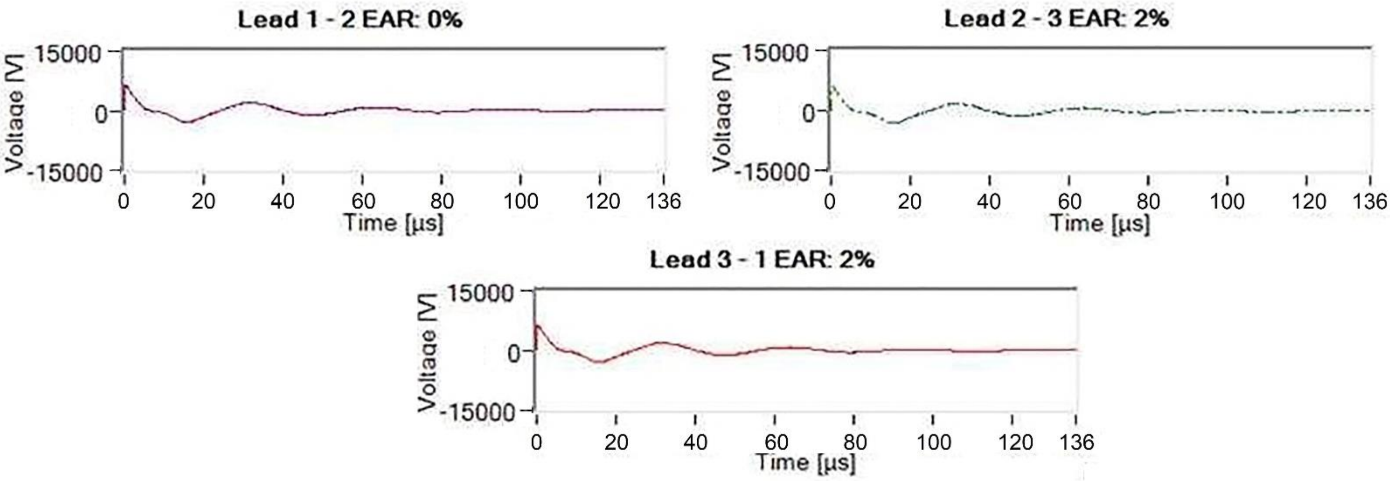

Figure 11. Stator Surge Test Graphics

4. CONCLUSION

As asynchronous motors are widely used in the cement industry, when undesirable situations are encountered, problems such as decreased product quality, increased energy use, labor losses, energy imbalance, increased maintenance costs, and decreased equipment efficiency are encountered in the process. Modern maintenance methods are applied in order to prevent and detect these problems in advance.

Predictive maintenance works, which is one of the modern maintenance methods, have been carried out and the areas that need to be maintained in the missing parts have been determined. Two high power induction motors are analyzed practically and theoretically by considering each parameter separately.

In this works; bearing cover clearance failures, unbalance, misalignment, misalignment, mechanical looseness, and light rotor friction were analyzed by vibration analysis. In electrical measurements, static and dynamic tests were performed; stator and rotor insulation resistance measurements, Hi-Pot, Surge tests, PI and DAR tests were performed and the types of faults were determined and improvement areas were identified.

In the dynamic analysis of the crusher-1 main drive motor, a dominant signal was observed in one direction depending on the direction in which the mass balance was disturbed, and this appears with vibration signals due to unbalance. Since the motor is connected to the load by belt and pulley system, the adjustment should be checked. As a side effect, the gaps in the bearing carrier covers also affect the signals, and the motor and load sides should be maintained and adjusted during the planned stop.

In the static test analysis of the main drive motor of the Cement Mill-3, it is observed that the insulation resistance (IR) is high and good. The pressing surfaces and distances of the coal holders to the ring are balanced. No arc marks and abrasion were observed on the ring surface. In the surge test, the resistance is above the standards. Wave frequencies between phases were observed equally.

In order to interpret the graphs in vibration analysis and electrical measurement tests, it will be useful for the working plant to determine the history and failure types of the equipment to be measured in advance.

Analyzing the graphs alone will not be sufficient for the investigations. In addition, knowledge of the process operation logic and the effects of structural and environmental sources on the equipment are among the important parameters for fault diagnosis.

One of the aspects that need to be improved for the business to continue to operate safely and smoothly is to ensure that failure does not recur. Recently, with the development of technology and competition, the philosophy of reliability-based maintenance has become widespread. In this philosophy, it is necessary to find the root cause of malfunctions and intervene in the equipment at the right time and to instill this philosophy by providing the necessary training to the personnel working on the equipment.

ACKNOWLEDGEMENT

This study has been produced from the master's degree dissertation of H. Çağtay ALKAYA.

REFERENCES

[1] Yıldız, A., Endüstri 4.0 ve Akıllı Fabrikalar, *Sakarya University Journal of Science*, 22 (2), 546–556, 2018. https://doi.org/10.16984/saufenbilder.321957

[2] Aydın, G., Meran, C., Çimento Sektöründe Kestirimci Bakımla Arıza Teşhisi ve Önlenmesi, *Mühendis ve Makina*, 59 (692), 48–67, 2018.

[3] Şahin, A., Büyük Güçlü Asenkron Motorlarda Titreşim Analizi ile Arıza Teşhisi, M. Sc. Thesis, Kocaeli University, Kocaeli, Turkey, 2018.

[4] Çavdarcı, M.A., Çimento sektöründe titreşim analizi ve kestirimci bakım yöntemleri, M. Sc. Thesis, Erciyes University, Kayseri, Turkey, 2021.

[5] Esen, G.K., Türkiye ve Dünyada Elektrik Motorları Enerji Tüketimi ve İlgili Teknik Mevzuat, Türk Standardları Enstitüsü. https://www.emo.org.tr/ekler/364734147179187_ek.pdf [Accessed: 21-Dec-2022].

[6] Uzun, H., Akar, O., Demirci, A., Aküner, M.C., Terzi, U.K., Analyzing High Efficiency Asynchronous Motors Using Scalar Control Technique, *Balkan Journal of Electrical and Computer Engineering*, 6, 23–26, 2018. https://doi.org/10.17694/bajece.410219.

[7] Kabul, A., Asenkron Motor Arızalarının Stator Akımı ve Titreşim Sinyalleriyle Analizi ve Tespiti, Ph.D. Thesis, Dumlupınar University, Kütahya, Turkey, 2022.

[8] Akbayır, K., Asenkron Motor Stator Arizalarinin Kaçak Akı Yöntemi İle Tespiti ve Prototip Geliştirilmesi, M.Sc. Thesis, Inonü University, Malatya, Turkey, 2022.

[9] Özelgin, İ., Asenkron Motor Arızalarının Dinamik Parametrelere Etkisi ve Frekans Analizi ile Tanısı, M.Sc. Thesis, Istanbul Technical University, Istanbul, Turkey, 2006.

[10] Çeven, S., Bayır, R., Bir Asenkron Motorun Mekanik Titreşim Sinyallerinin Ölçülerek Arıza Analizinin Yapılması, *European Journal of Science and Technology Special Issue*, 312–322, 2020. https://doi.org/10.31590/ejosat.780063.

[11] Güven, K., Periyodik Bakım Yapan Bir Tekstil İşletmesinde Bilgisayar Destekli Toplam Verimli Bakıma Geçiş ve Kaliteye Etkisi, M.Sc. Thesis, Erciyes University, Kayseri,Turkey, 2006.

[12] Sındır, E., Özkaner, V., Asenkron Motorlu Sistemde Bulanık Mantık Çıkarımı İle Kestirimci Bakım, *International Journal of Multidisciplinary Studies and Innovative Technologies*, 6 (2), 181–188, 2022.

[13] Göçülü, G., İşletmelerde Kestirimci Bakım Uygulamaları, M.Sc. Thesis, Mustafa Kemal University, Hatay, Turkey, 2015.

[14] Tazegün, A., Toplam Verimli Bakım ve Çimento Sektöründe Uygulamaları, M.Sc. Thesis, Trakya University, Edirne, Turkey, 2009.

[15] Ayan, O.A., Döner Makina Elemanların Titreşim Analizi ile Kestirimci Bakımı, M.Sc. Thesis, Trakya University, Edirne, Turkey, 2019.

[16] Vibscanner 2, https://www.pruftechnik.com/com/Products-and-Services/Condition-Monitoring-Systems/Vibration-Analysis-and-Balancing/Vibration-Analyzer/VIBSCANNER-2/ [Accessed: 01-Dec-2022].

[17] SKF Static Motor Analyzer Baker, http://skf.indpart.ru/images/upload/file/PUB-CM-71-030-EN-Baker DX-user-manual.pdf [Accessed: 03-Dec-2022].

BIOGRAPHIES

H.Çağtay ALKAYA completed his undergraduate education in Electrical and Electronics Engineering at Amasya University. He is also doing his master's degree in Electrical and Electronics Engineering, which is the same branch at Mehmet Akif Ersoy University. After completing his undergraduate education, he started his career in the energy and communication sector. In order to contribute to his professional development, he has been working in the field of electrical maintenance in cement factories, which are the pioneers of industrial facilities in various regions of Turkey. He is actively working in the fields of energy management, high voltage operation responsibility, and project management. In the field of maintenance, he has gained competence, especially in the maintenance of high-voltage asynchronous motors, and is doing his master's thesis in this field.

Sertaç GÖRGÜLÜ obtained his B.Sc. degree from Marmara University in 2001. In 2002, he started to work as a research assistant at Marmara University. He received his M.Sc. and Ph.D. degrees from Marmara

University in 2004 and 2011 respectively. Between 2009 and 2013, he worked at Kırklareli University in various titles. He has been working at Burdur Mehmet Akif Ersoy University since 2013. He works in the fields of natural and artificial lighting and design, renewable energy.