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Enhancing the Effective Performance of Critical Equipment's In Sugar Industry

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Abstract: The sugar industry has undergone significant changes in the past decade, with increased competition, rising costs and greater equipment complexity, while budgets, cane crushing days, operating margins, and maintenance staff have decreased. Any unexpected breakdowns of plant machineries can have a major effect on the availability and productivity of the whole plant. As a process industry, any failure in critical equipment can result in extended downtime, which directly affects the revenue generation of the entire plant. In this context, the maintenance department needs to demonstrate a positive impact on the sugar factories bottom line and necessitating the development or implementation of quality maintenance systems. A comprehensive condition-based maintenance program should incorporate a variety of technologies. While vibration monitoring is typically a key component of most condition-based maintenance programs, other monitoring and diagnostic techniques should also be included to provide a comprehensive approach in avoiding the unplanned sugar plant stoppages during crushing season.

I. INTRODUCTION

The regulated and integrated nature of the sugar industry, with its focus on rural development and diversification, has had a positive impact on the economic and social well-being of rural areas in India.

In the sugar industry, the maintenance department plays a crucial role in ensuring the overall performance of the factories during the crushing season. With increasing capacities and operational challenges, it becomes essential to develop a healthy maintenance system to minimize downtime, increase plant availability, and enhance productivity with higher quality standards. Equipment Performance Enhancement is an aggressive strategy that focuses on performance of existing equipment, its availability and effectiveness in order to make the business more profitable. By implementing this approach, the sugar factories can ensure better machinery availability, leading to improve overall performance.

The maintenance strategy in the sugar industry is vital to prevent equipment breakdowns during the cane crushing season. Poor maintenance practices can result in unnecessary wastage of resources such as manpower, machinery, and money. Lack of maintenance knowledge and skills among operators further adds to the challenges. Rotating machines, such as shafts, levers, bearings, gearboxes, couplings, electric motors, and belt drives, are integral components in the sugar industry. The healthy working conditions of these components significantly contribute to the overall machine performance. Therefore, ensuring proper maintenance and regular inspections of these components is crucial for maximizing machine efficiency and reducing breakdowns.

II. LITERATURE SURVEY

Vishnu Kv et al. [2] conducted a study on the causes of vibration in order to identify the underlying problems. They identified three main factors that contribute to vibration:

Repeating forces: Vibration in machines can be caused by repetitive forces acting on the machine due to improper, worn, or misaligned components. Imbalance accounts for approximately 40% of the vibration, misalignment for 30%, resonance for 20%, and the remaining 10% is attributed to other related issues. Imbalance can result from factors such as machining inaccuracies and non-uniform material density. Misalignment occurs due to inaccurate assembly of machine parts and thermal expansion.

Looseness: Vibration can also be caused by loose machine parts. When certain components become loose, it can lead to severe vibrations. Looseness can affect both rotating and non-rotating machinery, and loose bolts are a common cause of this issue.

Resonance: Each machine has its own natural oscillation rate, and when an external force is applied that matches this frequency, it amplifies the vibrations. This phenomenon is known as resonance.

The authors also emphasized the importance of vibration measurement and analysis using an accelerometer as a measurement device. The accelerometer is attached to the machine to measure its vibrations. It generates electrical signals, which are then

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converted into velocity signals. The captured signal can be viewed as a waveform or spectrum, and applying the Fast Fourier Transform on the velocity waveform allows for conversion to a velocity spectrum.

Harlisca Ciprian et al. [3] have discussed the condition monitoring of bearing faults. They categorized bearing faults based on their location, including inner race, outer race, balls, and cage, as well as the type of fault signature, such as single-point defects or generalized roughness.

Single point defect: Single-point defects result in periodic impulses in vibration signals. The amplitude and period of these impulses are determined by factors such as the rotational speed of the shaft, fault location, and bearing dimensions. As a result, each component of the bearing can be associated with a specific frequency. Generalized roughness fault: Generalized roughness fault is the most common cause of bearing failure. It often occurs in industrial environments due to various factors, including insufficient lubrication, contaminated lubricants, misalignment, abnormal environmental conditions like dust, water, acid, and humidity, and bearing corrosion caused by the presence of water and acids.

Sourabh Singh et al. [5] conducted a review of vibration analysis techniques for various rotating machines. These techniques were categorized into three groups: time domain, frequency domain, and time-frequency domain.

Time domain: Vibration signals are captured as a series of values representing proximity, velocity, or acceleration in the time domain.

The root-mean-square (RMS) value of a vibration signal is an example of a time domain feature. It provides information about the power content in the vibration and is useful in detecting imbalance in rotating machinery.

Frequency domain and time-frequency domain: Currently, frequency domain features and time-frequency domain features are widely employed in vibration analysis of rotating machines. Frequency domain features are generally more powerful and effective in indicating faults in rotating machinery compared to time domain features. This is because fault frequency components are more easily detected in frequency domain features compared to time domain features.

Within each category, a diverse range of techniques is presented. The authors conclude that frequency domain features are generally more effective in detecting faults compared to time domain features.

Pavan Kumar B K et al. [8] provided a brief overview highlighting the importance of condition-based monitoring (CBM). CBM is a maintenance technique that focuses on monitoring the condition or health of machinery or structures and provides recommendations for maintenance when necessary. The process involves collecting data from sensors attached to the system and analyzing it to derive meaningful information. Decision-making strategies are then employed to determine the appropriate timing for maintenance activities.

At the core of condition monitoring is fault diagnosis. Various techniques are implemented to detect and identify fault conditions in machines. By identifying faults at an early stage, CBM enables proactive maintenance interventions, reducing the time between maintenance activities (TBM) and the time required for repairs (MTTR). This leads to cost savings in terms of labor expenses and minimizes downtime losses in production.

III. THEORETICAL FRAMEWORK

A. Boiler Feed Water Pump

In the Boiler section of Sugar plant, the Boiler feed pump is one of the most critical auxiliary and is said to be the heart of the plant. The Boiler feed pump increases the Boiler feed water pressure to feed the same in the Boiler, where high pressure steam is generated which is used to drive a turbine, which in turn rotates the generator directly connected to turbine to generate electric power.

This means that any unexpected stoppage of BFP completely stops the Boiler, further stopping of power generation and therefore it is very required that Boiler feed pump are highly reliable and consistent in continuous operations.

B. Secondary Air Fan

Secondary air fans play a crucial role in the combustion process by providing additional air for complete combustion of fuel. They are designed to compensate for any untreated or insufficient primary air and ensure efficient and thorough combustion. Secondary air fans provide the necessary extra air for complete combustion of fuel. The controlled introduction of secondary air through furnace wall nozzles also aids in creating turbulence and facilitating uniform fuel feeding

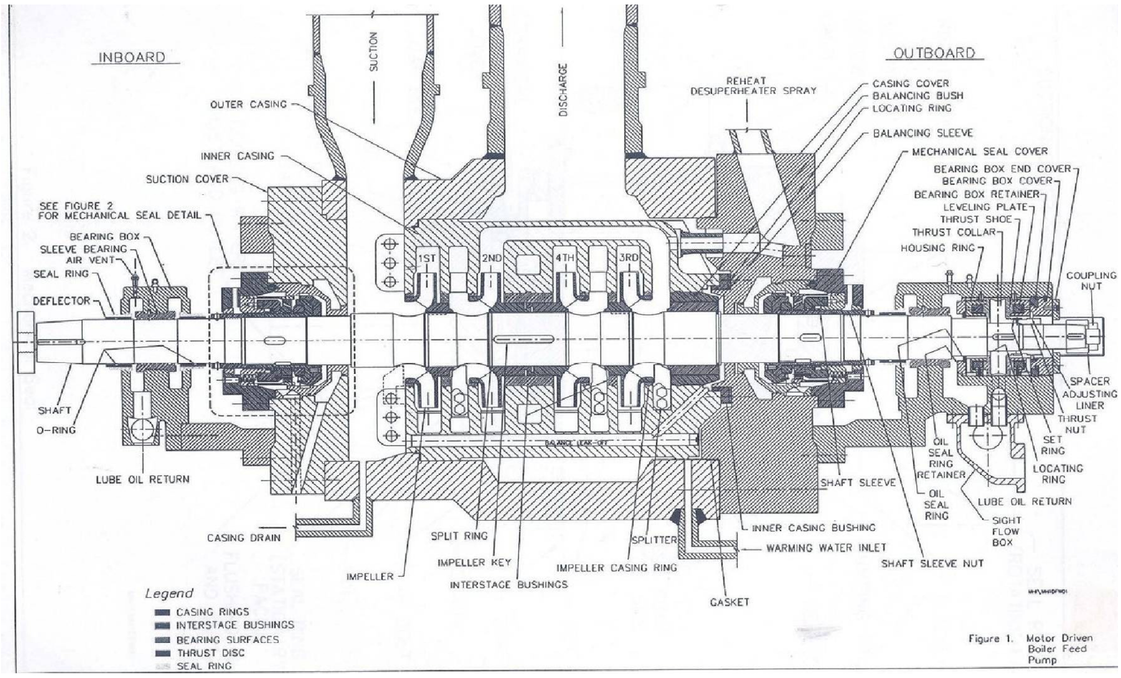

Figure 1: Boiler Feed Water Pump

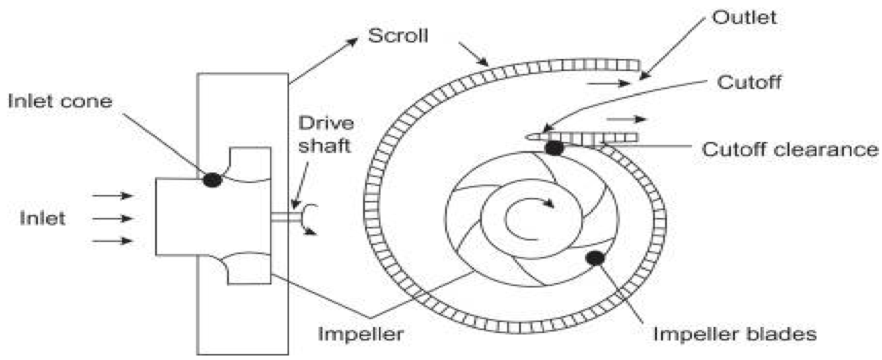

Figure 2: Secondary Air Fan

Table 1:- Technical specifications of Boiler Feed Pump

MAKE	KSB Pumps Ltd
MODEL	HGC 3/16 , multi stage
CAPACITY	79.6 Cub M /Hr,
RATED RPM	2980
OPERATING TEMPERATURE	120 ^{o} C
MAXIMUM HEAD DEVELOPED	1555 meter
TYPE OF FAN CONTROL	Variable Frequency Drive
TYPE OF DRIVE ADOPTED	Direct Coupled
COUPLING TYPE	Gear Coupling
MOTOR MAKE	Kirloskar Electric Company Ltd
RATING	956 Amp/ 590 kW
DRIVE END Bearing	6319C3

Table 2:- Technical specifications of Secondary Air Fan

MAKE	Flakt Woods
MODEL	Centrifugal, Aerofile
CAPACITY	34.3 Cub M /Sec Flow
BEARING	22220
RATED RPM	1440
OPERATING TEMPERATURE	190 ^{o} C
MAXIMUM HEAD DEVELOPED	605 mmWC
EFFICENCY OF FAN	82%
TYPE OF FAN CONTROL	Variable Frequency Drive
TYPE OF DRIVE ADOPTED	Direct Coupled
MOTOR MAKE	Kirloskar Electric Company Ltd
RATING	232 Amp/ 200 kW

C. General Relation Between Machine Frequency And Machine Fault

Vibration frequencies in bearings can provide valuable information about the condition and performance of the bearing components. There are four main types of vibration frequencies associated with bearings.

- *Ball Pass Frequencies:* Ball pass frequencies are related to the number of balls or rollers in the bearing and their rotational movement. The ball pass frequency of the inner race (BPFI) is the frequency at which the balls pass over a certain point on the inner race, while the ball pass frequency of the outer race (BPFO) is the frequency at which the balls pass over a certain point on the outer race. These frequencies are influenced by the rotational speed and geometry of the bearing.
- *Fundamental Train Frequency:* The fundamental train frequency (FTF) is the frequency at which the rolling elements (balls or rollers) make one complete revolution within the bearing. It is determined by the rotational speed of the bearing and the number of rolling elements. The FTF is an important frequency to monitor as it indicates the overall health and functioning of the bearing.
- *Ball/Roller Spin Frequency:* The ball/roller spin frequency (BSF/RSF) is the frequency at which the individual balls or rollers rotate around their own axis. This frequency is influenced by the rotational speed of the bearing and the number of rolling elements. Monitoring the BSF/RSF can provide insights into the condition of the rolling elements and their interaction with the raceways.

These vibration frequencies can be measured using various vibration analysis techniques, such as accelerometers or proximity probes. By analyzing the amplitude and frequency of vibrations, it is possible to detect abnormalities, such as bearing defects, misalignment, or lubrication issues. Monitoring these frequencies over time can help identify early signs of bearing degradation, allowing for proactive maintenance and preventing unexpected failures.

Failure Frequency Calculations For Boiler Feed Pump And Secondary Air Draft Fan For condition monitoring of feed pump and secondary draft fan vibration frequencies of machine are required. These frequencies are used to monitor the health of machine and diagnosis the actual problem in machine so that machine break down time should be reduced.

ISO-10816 has defined general relation between machine speed and machine fault as listed in table

Frequency	Cause	Comments
1 X N	Unbalance	A common cause of vibration.
1.5 X N	Bearing cage problem	May appear to be unbalanced. Shaft and bearing amplitude should be taken. If shaft vibration is larger than the bearing, vibration amplitude indicates clearance.
2 X N	Bearing looseness and parallel misalignment	Use phase analysis to determine relative movement of machine or bearings. Use a dial indicator if possible. Often diagnosed as a bent shaft.
n X N	Bearing problem	Use velocity measurement. Often affected by misalignment. Generally accompanied by side band frequency. Pitting, scuffing and fractures are often caused by torsional vibrations.

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1) Boiler Feed Pump (Vertical and Horizontal Direction)

Motor speed for feed pump (N1) - 2985 rpm = 49.75 Hz

Bearing number :- 7307 (Angular contact ball bearing.)

1) Case- I

Frequency is less than 49.75 Hz, Machine is in good condition.

2) Case-II

Frequency = 1 X N1

= 1 X 49.75 = 49.75 Hz

Defect :- Balancing problem

3) Case-III

Frequency = 1.5 X N1

= 1.5 X 49.75 = 74.625 Hz

Defect :- Bearing cage problem

4) Case-IV

Frequency = 2 X N1

= 2 X 49.75 = 99.5 Hz

Defect :- Bearing looseness and parallel misalignment

5) Case-V

Frequency = n1 X N1 (Where n- no of rolling element)

= 11 X 49.75 = 547.25 Hz

Defect:- Bearing problem

Ball pass frequency for Boiler Feed Pump

A) BPFO for feed pump $= n1X\frac{N1}{2}(1-\frac{Dr1}{Dp1}Cos\ \varphi)$ ------------------ (Equation-1)

$$= 11X\frac{49.75}{2}(1-\frac{0.5465}{2.2637}Cos90)$$

= 207.5667 Hz

B) BPFI for feed pump $= n1X\frac{N1}{2}(1+\frac{Dr1}{Dp1}Cos\ \varphi)$ ------------------ (Equation-II)

$$= 11X\frac{49.75}{2}(1+\frac{0.5465}{2.2637}Cos90)$$

= 339.6832 Hz

C) BSF for feed pump $= N1X\frac{Dp1}{Dr1}[1-(\frac{Dr1}{Dp1}Cos\ \phi)^2]$ ------------------ (Equation-III)

$$= 49.75X\frac{2.2637}{0.5465}[1-(\frac{0.5465}{2.2637}Cos90)^2]$$

= 194.0556 Hz

In equation 1, 2 and 3, Cosφ is contact angle of bearing.

Where, N1- Motor speed :- 49.75 Hz

n1 - Number of rolling element :- 11 nos.

Dp1- Pitch diameter of bearing :- 2.2637 inch

Dr1- Rolling element diameter :- 0.5465 inch

2) Secondary Draft Fan (Vertical And Horizontal Direction)

Motor speed for secondary draft fan (N2) - 1485 rpm

= 24.75 Hz

Bearing number :- 22220 EK/w3 (Double roller tapered spherical bearing.)

1) Case- I

Frequency is less than 24.75 Hz , Machine is in good condition.

2) Case-II

Frequency = 1 X N2

= 1 X 24.75 = 24.75 Hz

Defect:- Balancing problem

3) Case-III

Frequency = 1.5 X N2

= 1.5 X 24.75 = 37.125 Hz

Defect:- Bearing cage problem

4) Case-IV

Frequency = 2 X N2

= 2 X 24.75 = 49.5 Hz

Defect:-Bearing looseness and parallel misalignment

5) Case-V

Frequency = n2 X N2 (Where n is no of rolling element)

= 19 X 24.75 = 470.25 Hz

Defect:- Bearing problem

Ball Pass Frequency For Secondary Draft Fan

A) BPFO for secondary draft fan = $n2X\frac{N2}{2}(1-\frac{Dr2}{Dp2}Cos\ \varphi)$ ---------------- (Equation-IV)

$$=19X\frac{24.75}{2}(1-\frac{1.1024}{5.5118}Cos90)$$

= **188.0983 Hz**

B) BPFI for secondary draft fan = $n2X\frac{N2}{2}(1+\frac{Dr2}{Dp2}Cos\ \varphi)$ ------------------ (Equation-V)

$$=19X\frac{24.75}{2}(1+\frac{1.1024}{5.5118}Cos90)$$

=**282.1517 Hz**

C) BSF for secondary draft fan $=N2X\frac{Dp2}{Dr2}[1-(\frac{Dr2}{Dp2}Cos\phi)^2]$------------- (Equation-6)

$$=24.75X\frac{5.5118}{1.1024}[1-(\frac{1.1024}{5.5118}Cos90)^2]$$

= **118.7953 Hz**

In equation 4, 5 and 6, Cosφ is contact angle of bearing.

Where, N2- Motor speed :- 24.75 Hz

n2 - Number of rolling element:- 19 nos.

Dp2 - Pitch diameter of bearing :- 5.5118 inch

Dr2 - Rolling element diameter :- 1.1024 inch

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According to the fault cases MATLAB software has been designed according to above code. It will be show the result according to the fault case. After MATLAB code MATLAB application is created. In MATLAB application design the view by using component library. MATLAB main application will displays as shown in below. After showing below main application window click on 'Run tab'to enter in main application.

As shown in fig(3) MATLAB main appication path way, MATLAB ANN code path way is highlighted to open the main application function. After double click on main application tab it opens MATLAB main application window which shows in fig(4) MATLAB main application window. In this design view window will edit the tab as per our design view application. After that process run this application by clicking on Run tab. Now see the final design view of MATLAB main application as shown in fig(5).

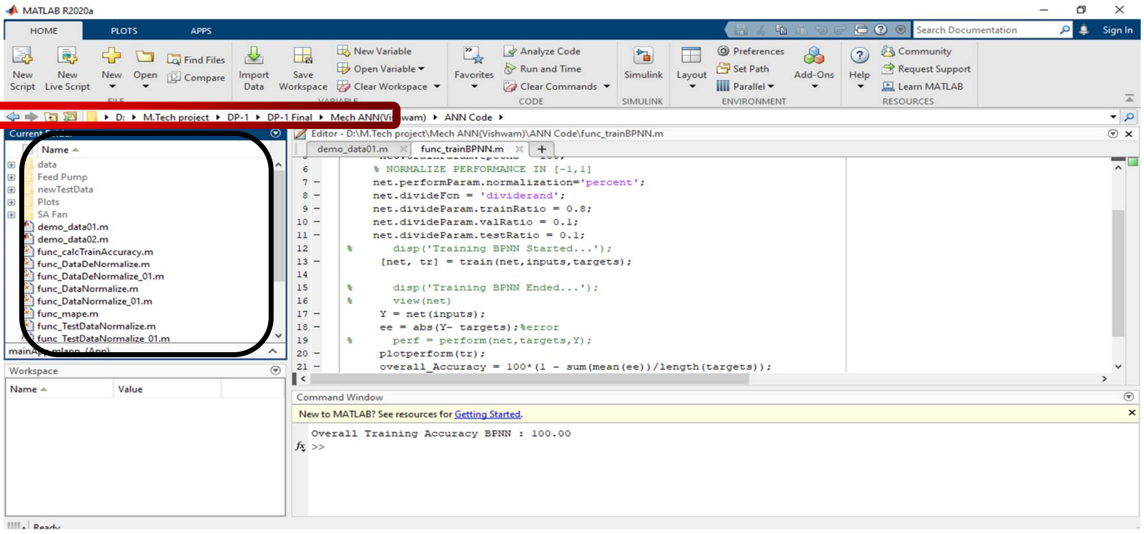

Figure 3: MATLAB main app path way

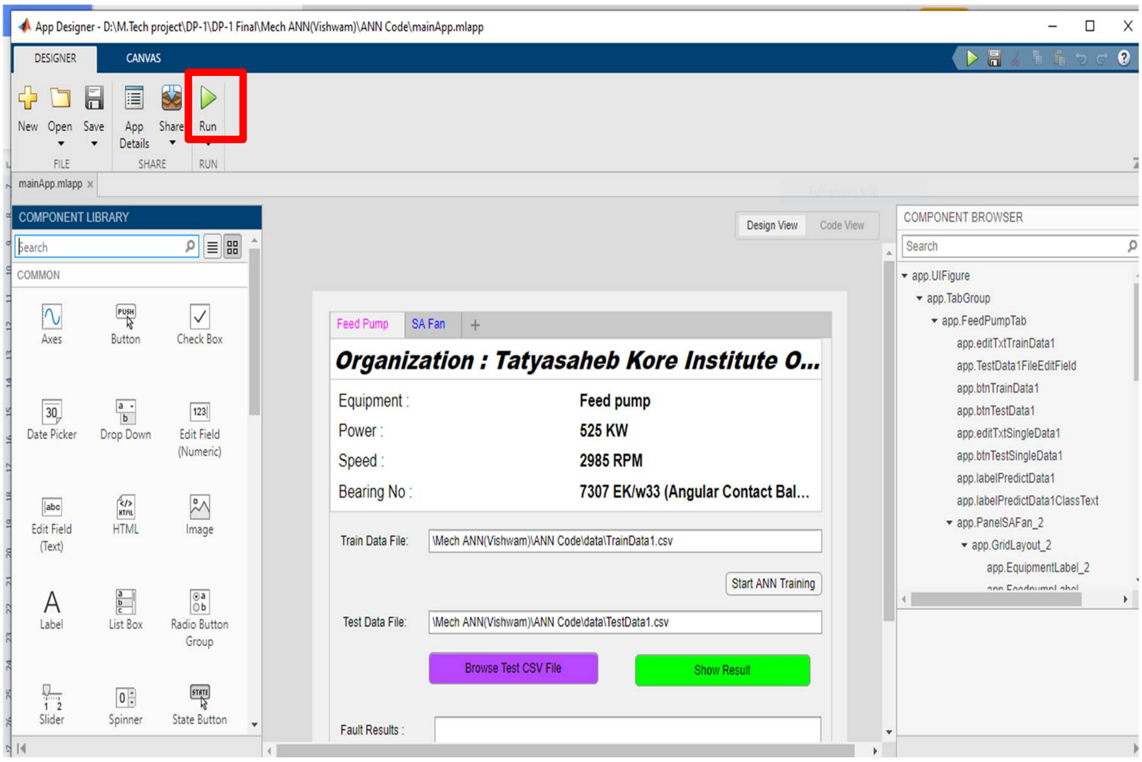

Figure 4: MATLAB main app window

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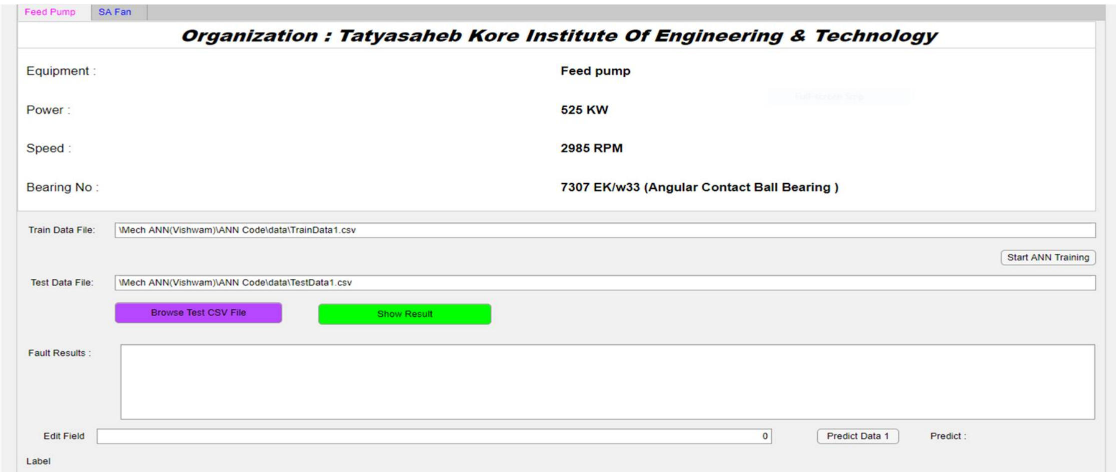

Figure 5: Design view of MATLAB main app

IV. PREPARATION OF TRAINING DATA

First software must be trained as per required result so that it can diagnosis the fault correctly. To train the software training data is arranged as shown below.

Table 3 : Training data for feed pump and SA fan

Feed pump				SA fan			
frequency	case	frequency	case	frequency	case	frequency	case
0.01264656	1	98.67	3	0.01222667	1	118.7953	5
13.99983	1	99.11	4	0.00801122	1	133.72	5
0.01292565	1	99.75	4	6.01299578	1	151.93	5
12.22667	1	190.45	4	0.01566242	1	158.88	5
0.01344649	1	195.55	5	3.01748703	1	169.39	5
0.00801122	1	204.89	5	24.75	2	175.75	5
5.1748703	1	208.81	6	26.62	2	188.0983	6
49.75	2	248.59	6	28.39	2	207.48	6
52.52	2	284.28	6	30.84	2	237.61	6
54.21	2	306.29	6	35.35	2	254.56	6
57.79	2	339.6832	7	37.125	3	272.39	6
59.87	2	342.45	7	39.96	3	280	6
65.55	2	344.67	7	41.12	3	282.1517	7
69.97	2	347.89	7	42.78	3	294.56	7
71.24	2	351.27	7	44.81	3	305.29	7
74.56	2	352.85	7	46.45	3	318.41	7
76.66	3	354.84	7	47.47	3	364.32	7
79.54	3	355.96	7	49.5	4	400.02	7
83.56	3	362.63	7	58.72	4	420.096	8
85.38	3	498.52	8	67.38	4	450.56	8
89.34	3	545.68	8	93.34	4	470.25	8
92.89	3	560.88	8	101.23	4	490.25	8
94.45	3	575.32	8	115.15	4	510.52	8

In above table frequencies arranged according to fault cases. MATLAB only knows the numbers according to it shows the result. Fault case and its description is mentioned in below table.

Table 4 : Vibration fault case and its description

Case	Description
1	Machine is in good condition
2	Balancing problem
3	Bearing cage problem
4	Bearing looseness and parallel misalignment
5	Bearing problem-C) Rolling element damage
6	Bearing problem-A) Outer race damage
7	Bearing problem-B)Inner race damage
8	Bearing problem

After preparing the data it needs to train it in MATLAB in following way. First select path for our train data file then click on start ANN training as shown in below.

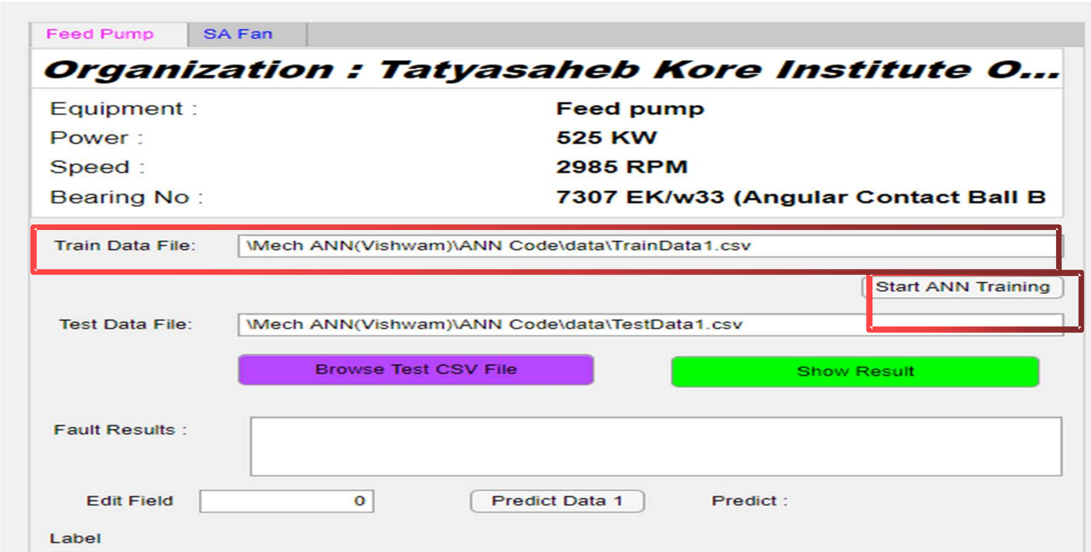

Figure 6 : ANN training data

Click on Start ANN training tab following window will be open which shows that the training is completed in MATLAB

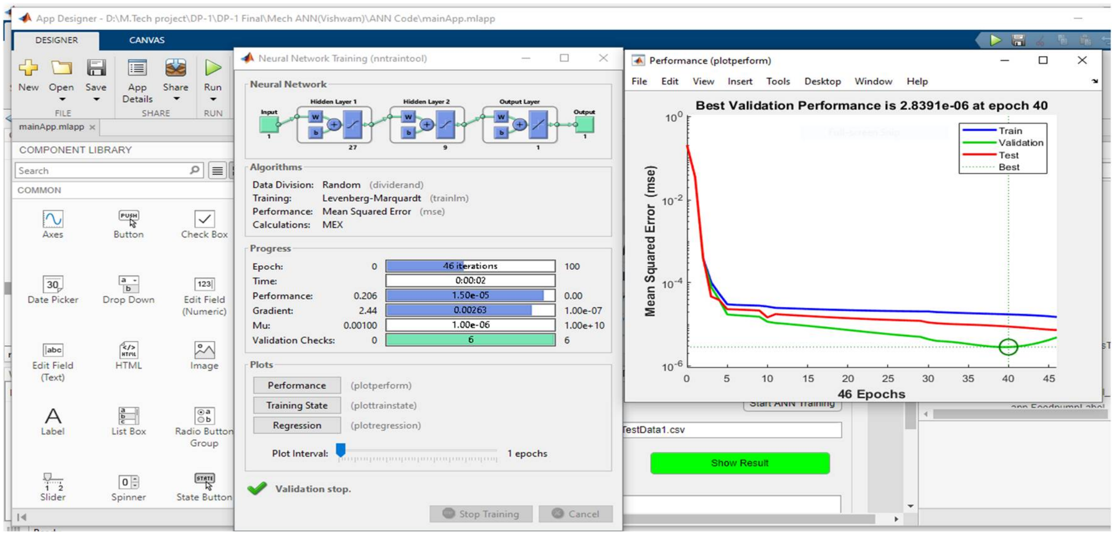

Figure 7 : Neural network training and performance graph

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V. PERFORMANCE AND VALIDATION OF MATLAB APPLICATION

In above steps MATLAB application is developed for this dissertation work. Now it should have to check that how this application is working and showing the perfect result. In above fig(5.5) Neural network training and performance graph, see the performance graph of MATLAB application. In this graph there are three curves shown by blue, red and green line. Blue line indicates the train data, red indicates the test data and green indicates validation data. From fig(5.6) regression graph, it shows that result is showing near to 100% efficiency so we can conclude that application is performing at its best level and giving correct results.

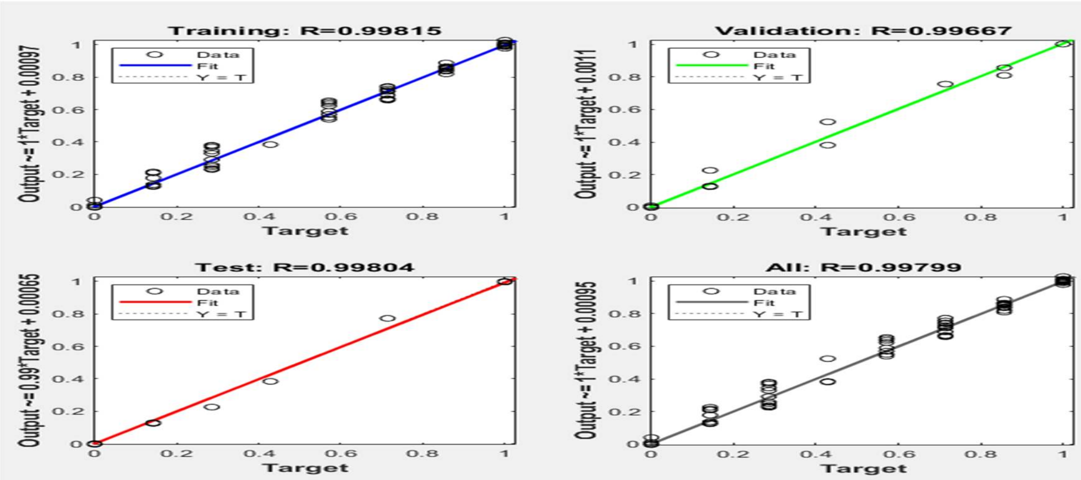
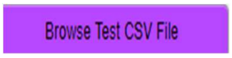


Figure 8 : Regression graph

A. Working of MATLAB app

At this level MATLAB application is ready to use. Now it is important to see that how it predict the result by browsing vibration frequencies sheet in software. In below fig(5.7) MATLAB app window, see the 

tab, after clicking on this tab one window will open from which select the test input file. After browsing test input file select 

tab. Now see that fault result dialogue box contains the fault data from excel sheet. This contain shows excel sheet number, vibration frequency and fault description is shown respectively.

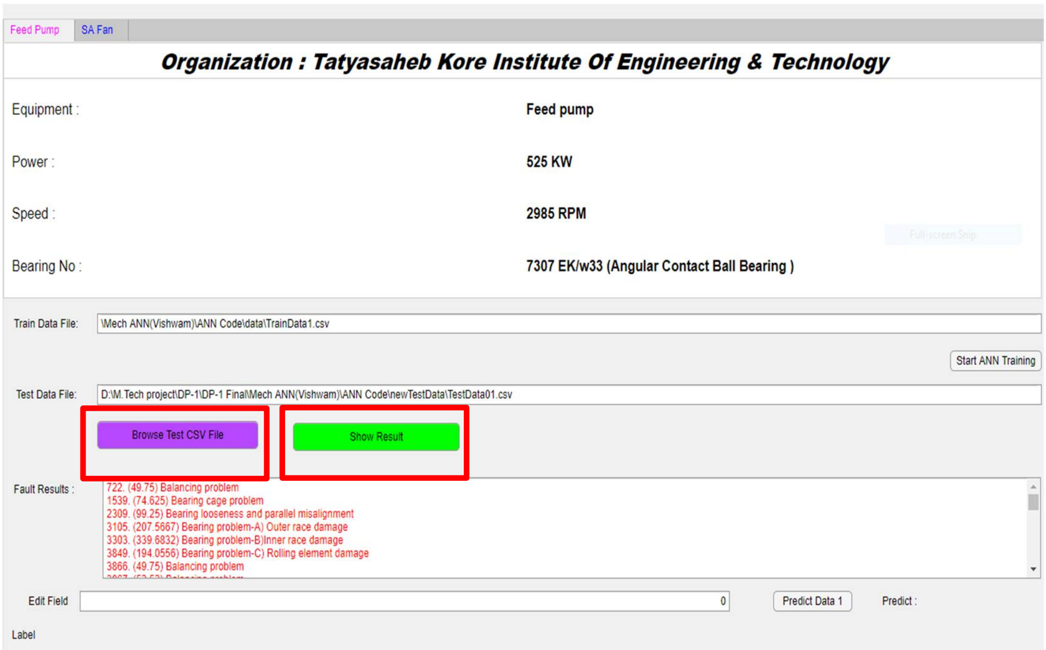


Figure 9 : MATLAB app window

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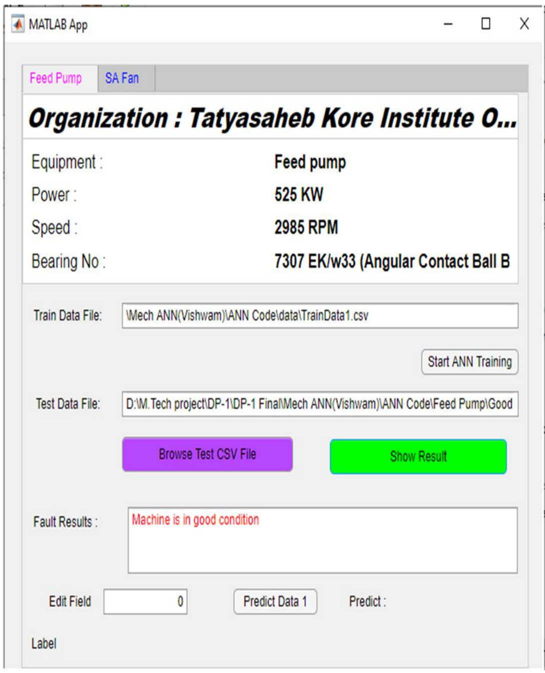
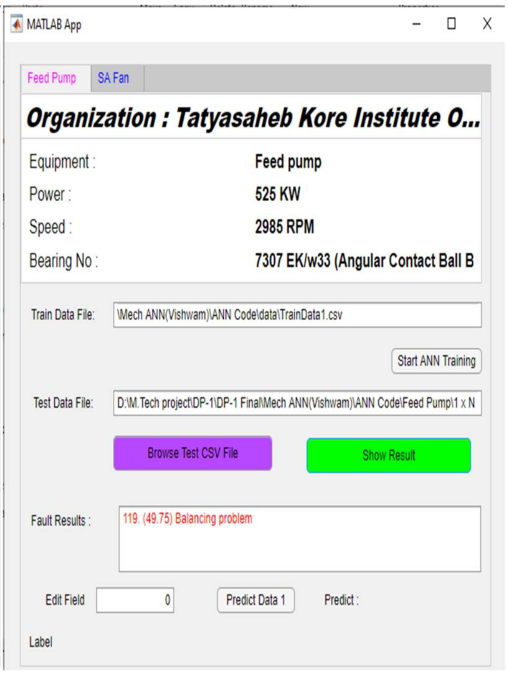
VI. DEVELOPMENT OF SOFTWARE

The developed MATLAB application has implimented for condition monitoring of feed pump and SA fan in URJANKUR SHREE TATYASAHEB KORE WARANA POWER COMPANY LIMITED.
The sample cases of result have been listed as below.

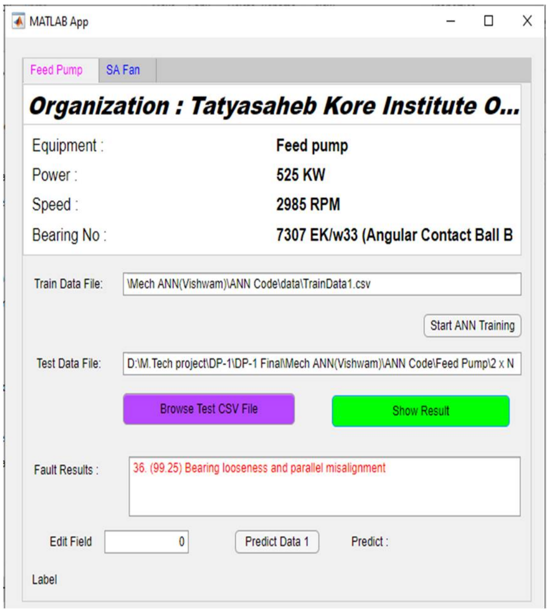
A. Sample Cases of Result for Feed Pump



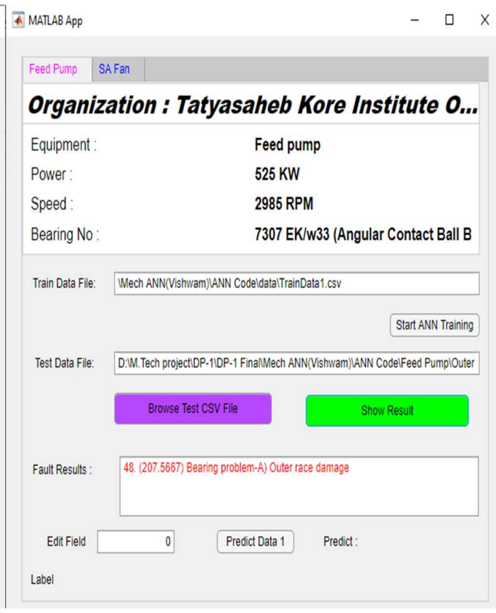
Machine is in good condition



Balancing problem

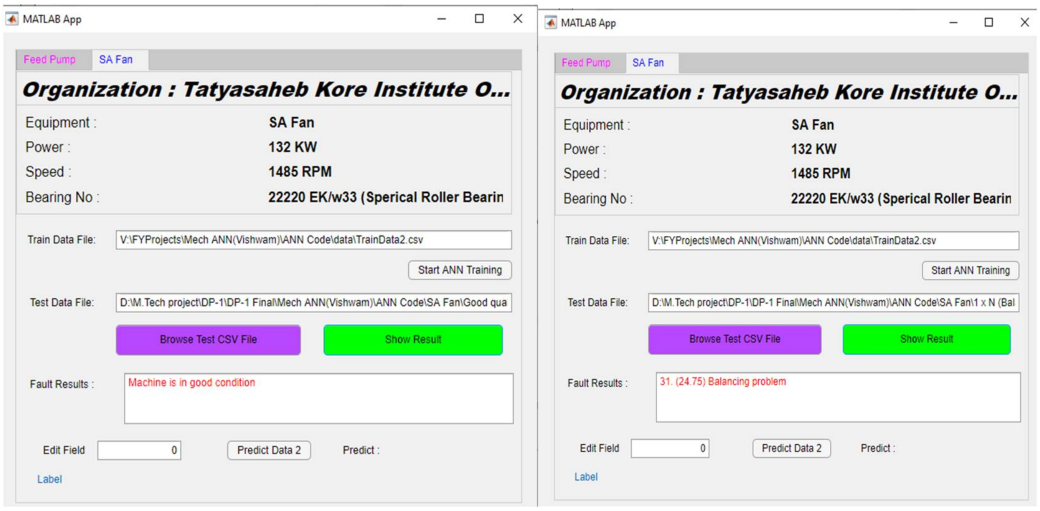


Bearing looseness and parallel misalignment

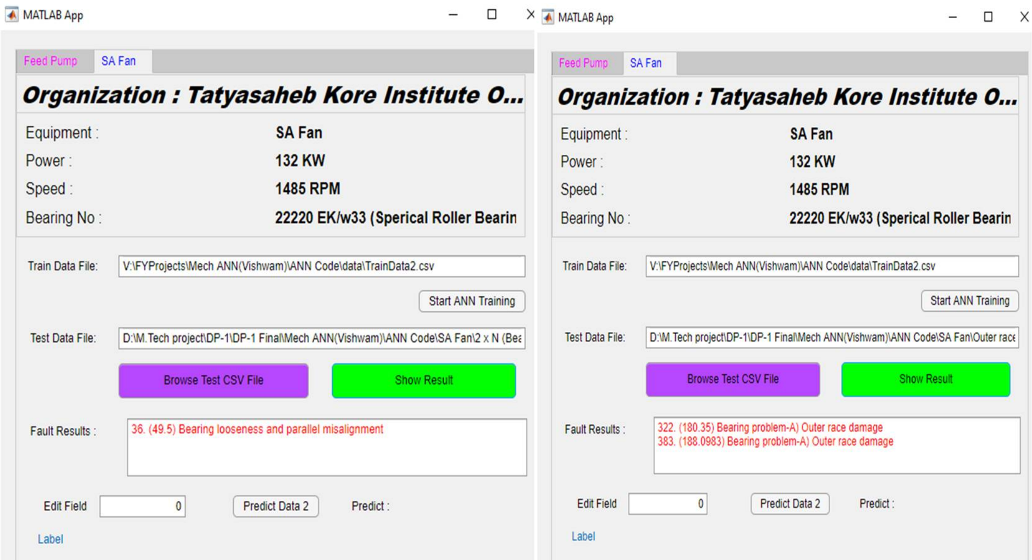


Bearing problem

Figure 10 :Sample cases of result for Feed Pump



Machine is in good condition Balancing problem



Bearing looseness and parallel misalignment Bearing problem

Figure 11 :Sample cases of result for SA fan

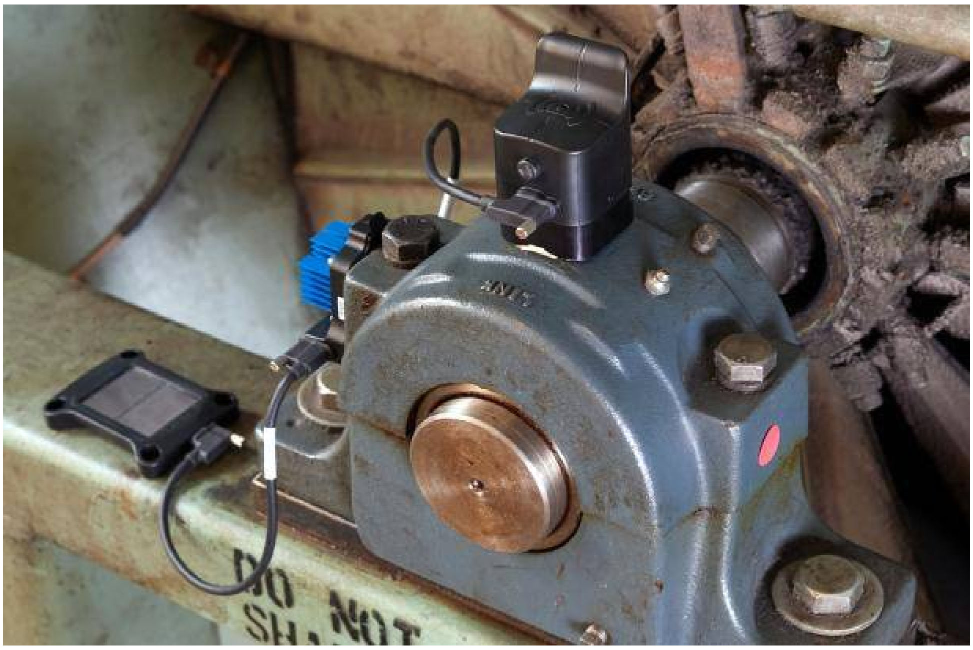
VII. RESULT AND CONCLUSION

In this project work it is decided to carry out condition monitoring of feed pump and secondary draft fan. FFT analyser is used to take the vibration signals from machines and MATLAB application is designed and developed to predict the actual machine fault. Machining fault can be diagnosis easily and it proceed further for maintanance. It reduces failure cost. This newly developed MATLAB application is successfully implimented in sugar industry to carry out condition monitoring of feed pump and secondary draft fan.

VIII. CONCLUSION

Following conclusions are drawn from this dissertation work

1) This software can allows easy monitor the machine fault before it produce severe brake down.
2) It avoids machine failure which may result in costly downtime and loose of men and money
3) MATLAB software is user friendly so that it can be easily handled by non technical person.
4) Implementation of this developed MATLAB software reduced the maintenance time as well as cost and increases the overall effectiveness of feed pump and secondary draft fan in sugar industry.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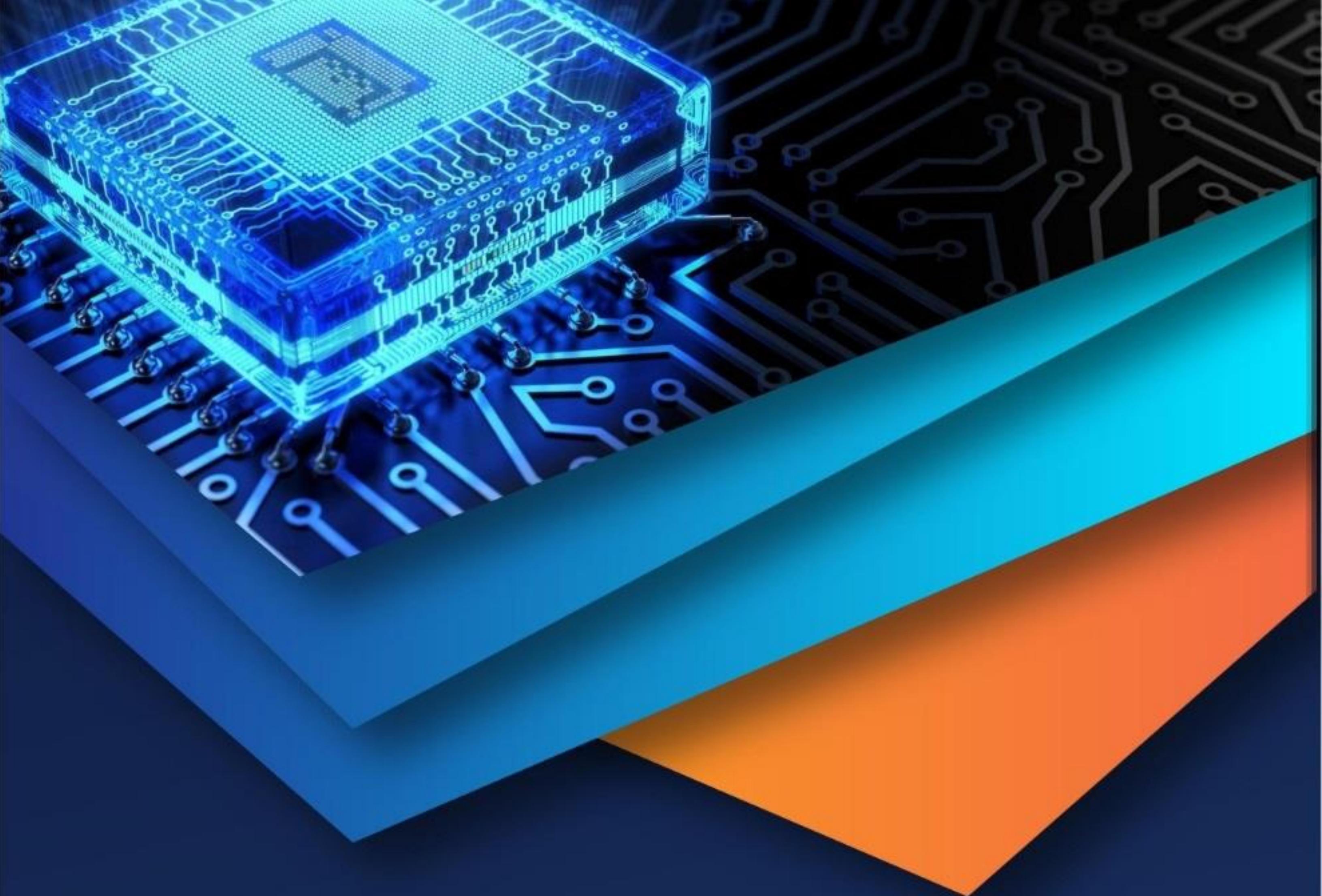

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