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Performance Analysis of Three Phase Induction Motor at PT. Intracawood Manufacturing

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Abstract_ To support the production process in an industry, there are many electric motor equipment in the form of induction motors. Induction motors are the most widely used motors in various fields, ranging from household environments to large-scale industries. Induction motors that are used continuously do not guarantee that they will always work normally, meaning that the motor can experience damage. These damages can affect the performance of the reduced induction motor. To find out the performance of the motor at PT. Intracawood Manufacturing, an analysis was carried out on the Blower Sander, Rotary, Conveyor Dry, and Conveyor Finishing motors, respectively on taking motor data based on the name plate and the motor in the current condition that was running or after rewinding. Motor performance analysis was conducted by calculating current, input power, output power, load torque, induction torque, and efficiency. From the calculation results, the Blower Sander motor by taking motor on the name plate with a current of 103 A, obtained an input power of 58.979 kW, an output power of 51.214 kW, an induction torque of 335.12 N.m, a load torque of 330.62 and efficiency of 86,83%. Meanwhile, the current motor condition with a current of 81.2 A, obtained input power of 43.945 kW, output power of 38.605 kW, induction torque of 254.7 N.m load torque of 250.23 N.m, and efficiency of 87.84%. Can be concluded, the performance of a three-phase induction motor at PT. Intracawood Manufacturing was a better is after rewinding.

Keywords: Induction Motor, Performance, Power, Torque, Efficiency.

I. INTRODUCTION

Induction motors are machines that convert electrical energy into mechanical energy. Induction motors are the most widely used motors in various fields, ranging from household environments to large-scale industry [1]. PT. Intracawood Manufacturing is an industrial company in the field of integrated woodworking to produce sawn timber, plywood, blockboard, timber molding, and others related to woodworking. In the production process, it uses a three-phase induction motor as the main drive. This is because induction motors have several advantages over other types of motors [2].

When the motor continues to operate, it also causes several problems, such as a decline in motor performance and damage to the components of the induction motor. Damage can be caused by operational errors, poor maintenance, overload, unbalanced load, and aging factors [3]. These damages can affect the overall performance of the induction motor. One way to maintain induction motors is through rewinding [4], which is also considered a cost-effective method in industrial maintenance to avoid replacing the entire motor system.

Rewinding is one of the coil repair processes on the induction motor stator. It is generally carried out by referring to the nameplate data. The winding planning method must consider several factors, including wire diameter, number of windings, number of slots per phase, slot pitch, phase sequence, and winding connection, which serve as the final determinant of induction motor performance [5].

Several studies related to the performance of induction motors have been carried out. For instance, in [6], an analysis of the performance of a 2.2 kW three-phase induction motor at PT Max Power

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Indonesia was conducted by comparing new and rewound motor performance through calculation of stator current, rotor current, torque, and efficiency, followed by simulation using Simulink MATLAB R2007b. Another study in [7] analyzed the efficiency of three-phase induction motors due to voltage changes through resistance tests, no-load tests, load tests, and locked-rotor tests, also simulated in MATLAB. In [8], researchers analyzed a three-phase induction motor's performance driving a centrifugal pump at Favehotel Rungkut Surabaya by calculating power, efficiency, and torque under minimum, half, and full loads.

Recent studies in electric machine systems also highlight the importance of optimizing electrical device performance through control and simulation strategies [10]–[14]. These include solar PV systems [12], electric bicycle battery charging systems [11], DC motor speed control [14], and harmonic correction on LED lighting [10].

This study aims to determine the efficiency and performance of a three-phase induction motor in its initial condition (based on the nameplate) and its current condition after rewinding. Induction motor performance can be assessed from current, power, torque, and efficiency.

II. METHODS

In research analyzing the performance of three-phase induction motors at PT. Intracawood Manufacturing using a quantitative approach. This quantitative research uses survey research methods. Based on Figure 1 the stages of this research are as follows.

[Figure 1 about here.]

2. 1 Literature Study

The initial stage carried out in this research is a literature study, namely by reading and studying books, scientific papers, journals and other sources from the internet related to the research theme. Literature study as a reference in conducting research preparation, related to what things will be done in the preparation and research.

2. 2 Measurements and Collection Data

The author will take measurements and collect data on a three-phase induction motor. Measurements are made using several tools including volt meters to measure voltage, ampere meters to measure current, and tacho meters to measure the rotation speed of induction motors. The required data include voltage, current, and rotation of three-phase induction motors both in taking motor data based on the name plate and motors that have been rewinding.

2. 3 Calculation and Data Analysis

Calculations carried out in the form of input power, output power, induction torque, load torque, and efficiency of three-phase induction motors. From the calculation results, the author will analyze the data. The data analysis carried out is related to the performance of a three-phase induction motor. To determine the input power, use the equation [9].

$$P_{in} = \sqrt{3}\, V_L I_L \cos\theta \quad (1)$$

Where the input power is in Watts, V_L is the source voltage in Volts, I_L is the source current in amperes, and $\cos\theta$ is the power factor of the induction motor. Before determining the output power, the author determines the stator copper power loss (P_{SCL}) on the induction motor, using the equation [9].

$$P_{SCL} = 3 \times I_1^2 \times R_1 \quad (2)$$

Where the stator copper power loss is in Watts, I_1 is the stator current in amperes, and R_1 is the stator resistance in Ohms. To determine the power losses delivered by the air gap (P_{AG}) on the induction motor, use the equation [9].

$$P_{AG} = P_{in} - P_{SCL} \quad (3)$$

Where the air gap power loss is in units of Watt. This study also determines the stator speed (N_S) and slip of the induction motor, using the equation:

$$N_S = \frac{120.f}{4} \quad (4)$$

Where the stator rotating field speed is in units of rpm and f is the frequency in Hz. To determine the slip on an induction motor using the equation:

$$S = \frac{N_S - N_r}{N_S} x\ 100\% \quad (5)$$

Where slip is in percent and Nr is the rotor speed in rpm. To determine the rotor copper power loss (P_{RCL}) in an induction motor, use the equation [9].

$$P_{RCL} = S \times P_{AG} \quad (6)$$

Where is the copper rotor power loss in units. To determine the mechanical power loss (P_{conv}) in an induction motor, use the equation [9].

$$P_{conv} = (1 - S) \times P_{AG} \quad (7)$$

Where mechanical power loss is in units of Watt. To determine the output power (P_{out}) of an induction motor, use the equation [9].

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$$P_{out} = P_{conv} - P_{RCL} \quad (8)$$

Where the output power is in units of Watt. Before determining the induction torque, it can be done by determining the rotational angular velocity on the stator (ω_s), using the equation [9].

$$\omega_s = \frac{N_s}{60} \times 2\pi \quad (9)$$

Where the rotational angular velocity of the stator is in units of rad/s. To determine the induction torque on an induction motor, use the equation [9].

$$T_{ind} = \frac{P_{AG}}{\omega_s} \quad (10)$$

Where the induction torque is in units of N.m. Before determining the load torque, it can be done by determining the rotational angular velocity on the stator (ω_r), using the equation [9].

$$\omega_r = \frac{N_r}{60} \times 2\pi \quad (11)$$

Where the rotor rotational angular speed is in units of rad/s. To determine the load torque on an induction motor, it can be determined using the equation [9].

$$T_{load} = \frac{P_{out}}{\omega_r} \quad (12)$$

Where the load torque is in units of N.m. To determine the efficiency using the equation [9].

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (13)$$

Where efficiency is in percent. The efficiency of a machine is a measure of how well it can convert electrical input energy to mechanical output energy.

After data analysis has been carried out, the authors draw conclusions. Conclusions are drawn regarding the efficiency and performance of the induction motor in the initial condition based on the name plate and the current condition or after rewinding.

III. RESULTS AND DISCUSSION

The research conducted uses 4 motors, namely motors on Blower Sander, Rotary, Conveyor Dry, and Conveyor Finishing machines. The Blower Sander motor functions to suck the remaining sanding powder and then send it to the Blower, Rotary functions to arrange the plywood sheets that have been peeled in Rotary, Conveyor Dry to move the material after the wood is dried and Conveyor Finishing to move the plywood material that has gone through the Finishing process. The data used is data on the motor name plate that is measured and data on the current motor condition that is running or after rewinding at PT. Intracawood Manufacturing.

3. 1 Input Power on Induction Motor

The data used to calculate the input power is the value of voltage, current, and cos φ. The following is the three phase induction motor measurement data addressed in Table 1.

[Table 1 about here.]

Calculation to find the input power value (P_{in}), with Equation (1).

$$P_{in} = \sqrt{3}\, V_L I_L \cos\theta$$
$$P_{in} = \sqrt{3} \times 380 \times 103 \times 0{,}87$$
$$P_{in} = 58.979{,}447 \text{ Watt}$$

By using the same equation based on the data in Table 1, the input power value is obtained as shown in Table 2.

[Table 2 about here.]

Based on Table 2, the largest input power value is on the Blower Sander motor. Blower Sander input power is greater, this is because the Blower Sander motor has a power of 75 Horse Power (HP). While the power in the Rotary motor is 20 HP, Conveyor Dry is 7.5 HP, and Conveyor Finishing is 3 HP. Power is directly proportional to current. The greater the power, the greater the current in the motor. Comparison of three-phase induction motor performance based on current in Figure 2. Where the value of motor current is in Table 1.

[Figure 2 about here.]

Based on Figure 2, it can be seen that the motor current in the initial condition is greater than the current condition. This is because the initial condition is the maximum current that can be borne by the motor. Current is directly proportional to voltage and inversely proportional to resistance. Resistance is directly proportional to density and cross-sectional area, and inversely proportional to wire length. When the resistance is large, the current is small.

Comparison of three-phase induction motor performance based on power in Figure 3. Where the calculation results of input power are in Table 2.

[Figure 3 about here.]

Based on the figure, it can be seen that the input power on the initial condition motor is greater than the current condition. The input power is directly proportional to the current. When the current is greater, the input power will also be large.

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3. 2 Power Losses in Induction Motors

The data required in the calculation of power losses are current, frequency, rotor rotation speed (*Nr*), and input power. The following data is used in the calculation of power losses in Table 3.

[Table 3 about here.]

In Table 3 the frequency of the Blower Sander motor is 36 Hz. This is because the Blower Sander motor uses a Variable Speed Drive (VSD) as a motor rotation speed regulation by changing the frequency value. Calculating stator copper power loss (P_{SCL}) can be determined by Equation (2).

$$P_{SCL} = 3 \times I_1^2 \times R_1$$
$$P_{SCL} = 3 \times (103)^2 \times 0{,}2$$
$$P_{SCL} = 6.365{,}4 \text{ Watt}$$

The author calculates the power loss delivered at the air gap (P_{AG}), in Equation (3).

$$P_{AG} = P_{in} - P_{SCL}$$
$$P_{AG} = 58.979{,}447 - 6.365{,}4$$
$$P_{AG} = 52.614{,}047 \text{ Watt}$$

Next, the author will find the value of the stator speed (N_S), in Equation (4).

$$N_S = \frac{120.f}{4}$$
$$N_S = \frac{120.50}{4}$$
$$N_S = 1500\ rpm$$

After knowing the stator speed, the author will find the slip on the induction motor. To find the slip, in Equation (5).

$$S = \frac{N_s - N_r}{N_s} x\ 100\%$$
$$S = \frac{1500 - 1480}{1500} x100\%$$
$$S = 1{,}33\%$$

Calculate the rotor copper power loss (P_{RCL}), in Equation (6).

$$P_{RCL} = S \times P_{AG}$$
$$P_{RCL} = 0{,}0133 \times 52.614{,}047$$
$$P_{RCL} = 699{,}7668 \text{ Watt}$$

Calculate the mechanical power loss (P_{conv}), in Equation (7).

$$P_{conv} = (1 - S) \times P_{AG}$$
$$P_{conv} = (1 - 0{,}0133) \times 52.614{,}047$$
$$P_{conv} = 51.914{,}28 \text{ Watt}$$

By using the same equation based on the data in Table 3, the power loss values in Table 4 are obtained.

[Table 4 about here.]

In an induction motor, there are several losses caused by the components of the motor itself. These components can cause losses such as stator copper power (P_{SCL}), power losses sent to the air gap (P_{AG}), rotor copper power losses (P_{RCL}), and mechanical power losses (P_{conv}). In copper losses occur due to the current value and resistance of the copper coil. Thus, the greater the current flowing, the greater the power loss in the motor.

3. 3 Output Power on Induction Motor

After calculating the power losses in Table 4, the output power (P_{out}) of the induction motor can be determined. To determine the output power can be determined by Equation (8) using the P_{conv} and P_{RCL} data in Table 4.

$$P_{out} = P_{conv} - P_{RCL}$$
$$P_{out} = 51.914{,}28 - 699{,}7668$$
$$P_{out} = 51.214{,}513 \text{ Watt}$$

By using the same equation based on the P_{conv} and P_{RCL} data in Table 4, the output power is obtained in Table 5.

[Table 5 about here.]

Comparison of three-phase induction motor performance based on output power in Figure 4, where the results of the output power calculation are in Table 5.

[Figure 4 about here.]

Based on Figure 4, the output power in the initial condition is greater than in the current condition. The output power on the induction motor is influenced by the power losses that occur in the motor. The greater the power loss, the less output power is produced.

3. 4 Induction Torque on an Induction Motor

Calculating the stator rotational angular speed of an induction motor can be determined by Equation (9).

$$\omega_s = \frac{N_s}{60} \times 2\pi$$
$$\omega_s = \frac{1500}{60} \times 2\pi$$
$$\omega_s = 157\ rad/s$$

To determine the induction torque can be determined by Equation (10).

$$T_{ind} = \frac{P_{AG}}{\omega_s}$$
$$T_{ind} = \frac{52.614{,}047}{157}$$
$$T_{ind} = 335{,}12\ N.m$$

By using the same equation based on the calculation results of the stator rotational angular velocity (N_S) and the power losses delivered at the air gap (P_{AG}) in Table 4, the values of the rotational angular velocity on the stator (ω_s) and the induced torque on the induction motor are obtained as in Table 6.

[Table 6 about here.]

Comparison of three-phase induction motor performance based on motor induction torque in Figure 5. Where the results of the calculation of motor induction torque are in Table 6.

[Figure 5 about here.]

Based on Figure 5, the induced torque in the initial condition is greater than the current condition. Induction torque is directly proportional to the power loss in the air gap. In the initial condition motor, the air gap power loss is greater than the current condition motor. So that the induction torque on the initial condition motor is greater than the current condition.

3. 5 Load Torque on Induction Motor

Calculating the rotational angular velocity of the induction motor stator can be determined in Equation (10).

$$\omega_r = \frac{N_r}{60} \times 2\pi$$
$$\omega_r = \frac{1480}{60} \times 2\pi$$
$$\omega_r = 154{,}9\ rad/s$$

To determine the load torque can be determined by Equation (12).

$$T_{load} = \frac{P_{out}}{\omega_r}$$
$$T_{load} = \frac{51.214{,}513}{154{,}9}$$
$$T_{load} = 330{,}62\ N.m$$

By using the same equation based on the measurement results of the rotor rotational speed (N_r) in Table 3 and the calculation results of the output power in Table 5, the values of the speed on the rotor (ω_r) and the load torque on the induction motor are obtained as in Table 7.

[Table 7 about here.]

Comparison of three-phase induction motor performance based on motor load torque in Figure 6. Where the calculation results of motor load torque are in Table 7.

[Figure 6 about here.]

Based on Figure 6, the load torque on the initial condition motor is greater than the current condition. The load torque is directly proportional to the output power. The greater the output power the greater the load torque.

3. 6 Efficiency in Induction Motor

After knowing the input power and output power of the induction motor, the motor efficiency can be determined by Equation (13).

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$
$$\eta = \frac{51.214{,}513}{58.979{,}447} \times 100\%$$
$$\eta = 86{,}83\%$$

By using the same equation based on the input power values in Table 2 and the output power in Table 5, the induction motor efficiency is obtained in Table 8.

[Table 8 about here.]

Comparison of three-phase induction motor performance based on motor efficiency in Figure 7. Where the results of the calculation of motor efficiency are in Table 8.

[Figure 7 about here.]

Based on Figure 7, the efficiency of the motor in the current condition is greater than the initial condition. In general, after rewinding, the efficiency of induction motors tends to decrease. This decrease is caused by factors such as winding technique, conductor material type, insulation quality, and operating temperature. However, by performing the rewinding process properly, motor efficiency can be maintained or even increased in some cases by changing the winding design, for example by using a wire that has a larger cross section. This can reduce stator losses and improve motor efficiency.

IV. CONCLUSION

Based on the results of measurements and calculations on the performance analysis of three-phase induction motors on Blower Sander, Rotary, Conveyor Dry, and Conveyor Finishing motors. Then the results obtained on the Blower Sander motor with initial conditions obtained a current of 103 A, input power 58.979 kW, output power 51.214 kW, induction torque 330.62 N.m, load torque 330.62 and efficiency 86.83% on the current condition motor obtained a current of 81.2 A, input power 43.945 kW, output power 38.605 kW, induction torque 254.7 N.m, load torque 250.23 N.m, and efficiency 87.84%. So it can be concluded that the performance of the three-phase induction motor at PT. Intracawood Manufacturing is better in the current condition or after rewinding.

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Table 1. Measurements data of voltage, current, and cos φ on induction motors

No.	Condition	Load	Voltage (V)	Current (A)	Cos φ
1.	Based on Name Plate	Blower Sander	380	103	0,87
		Rotary	380	29,1	0,865
		Conveyor Dry	380	12	0,85
		Conveyor Finishing	380	5,18	0,85
2.	Currently in Operation	Blower Sander	367,6	81,2	0,85
		Rotary	358,3	7,7	0,845
		Conveyor Dry	371,4	4,82	0,86
		Conveyor Finishing	384,2	2,2	0,99

Table 2. Calculation results of input power on induction motor

No.	Condition	Load	P_{in} (Watt)
1.	Based on Name Plate	Blower Sander	58.979,44
		Rotary	16.567,36
		Conveyor Dry	6.713,42
		Conveyor Finishing	2.897,96
2.	Currently in Operating	Blower Sander	43.945,16
		Rotary	4.037,89
		Conveyor Dry	2.670,96
		Conveyor Finishing	1.449,35

Table 3. Measurement result of current, frequency, rpm, and input power

No.	Condition	Load	Current (A)	Frequency (Hz)	Nr (Rpm)	P_{in} (Watt)
1.	Based on Name Plate	Blower Sander	103	50	1480	58.979,44
		Rotary	29,1	50	1470	16.567,36
		Conveyor Dry	12	50	1445	6.713,42
		Conveyor Finishing	5,18	50	1435	2.897,96
2.	Currently in Operating	Blower Sander	81,2	50	1474	43.945,16
		Rotary	7,7	36	1063	4.037,89
		Conveyor Dry	4,82	52	1534	2.670,96
		Conveyor Finishing	2,2	50	1497	1.449,35

Table 4. The results of the calculation of power losses in induction motors

No.	Condition	Load	N_S (rpm)	S (%)	P_{SCL} (Watt)	P_{AG} (Watt)	P_{RCL} (Watt)	P_{conv} (Watt)
1.	Based on *Name Plate*	Blower Sander	1500	1,33	6.365,4	52.614,04	699,76	51.914,28
		Rotary	1500	2	1.270,21	15.297,14	305,94	14.991,2
		Conveyor Dry	1500	3,67	864	5.849,42	214,67	5.638,84
		Conveyor Finishing	1500	4,33	434,68	2.463,16	106,65	2.356,5
2.	Currently in Operating	Blower Sander	1500	1,73	3.956,06	39.989,09	691,81	39.297,24

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Rotary	1080	1,13	88,93	3.948,95	44,75	3.904,32
Conveyor Dry	1560	1,67	139,85	2.531,10	42,18	2.488,83
Conveyor Finishing	1500	0,2	78,40	1.370,94	2,74	1.368,19

Table 5. Results of output power calculation on induction motor

No.	Condition	Load	P_{out} (Watt)
1.	Based on Name Plate	Blower Sander	51.214,15
		Rotary	14.685,25
		Conveyor Dry	5.424,17
		Conveyor Finishing	2.249,85
2.	Currently in Operating	Blower Sander	38.605,43
		Rotary	3.859,57
		Conveyor Dry	2.446,64
		Conveyor Finishing	1.365,45

Table 6. Calculation results of rotational angular velocity on the stator (ω_s) and induction torque of the induction motor

No.	Condition	Load	$\omega_s\ (rad/s)$	$T_{ind}\ (N.m)$
1.	Based on Name Plate	Blower Sander	157	335,12
		Rotary	157	97,43
		Conveyor Dry	157	37,25
		Conveyor Finishing	157	15,68
2.	Currently in Operating	Blower Sander	157	254,7
		Rotary	113,04	34,93
		Conveyor Dry	163,28	15,5
		Conveyor Finishing	157	8,73

Table 7. The calculation results of the rotational angular velocity on the rotor (ω_r) and the load torque of the induction motor

No.	Condition	Load	$\omega_r\ (rad/s)$	$T_{load}\ (N.m)$
1.	Based on Name Plate	Blower Sander	154,9	330,62
		Rotary	153,86	95,44
		Conveyor Dry	151,24	35,86
		Conveyor Finishing	150,19	14,98
2.	Currently in Operating	Blower Sander	154,27	250,23
		Rotary	111,26	34,68
		Conveyor Dry	160,55	15,23
		Conveyor Finishing	156,68	8,71

Table 8. Induction motor efficiency calculation results

No.	Condition	Load	η (%)
1.	Based on Name Plate	Blower Sander	86,83
		Rotary	88,63
		Conveyor Dry	80,79
		Conveyor Finishing	77,6

2.	Currently Operating	Blower Sander	87,84
		Rotary	95,58
		Conveyor Dry	91,6
		Conveyor Finishing	94,2

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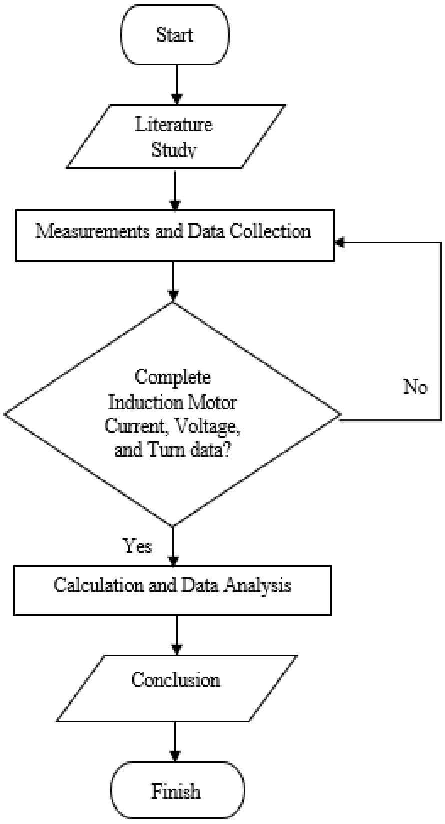

Figure 1. Research flowchart

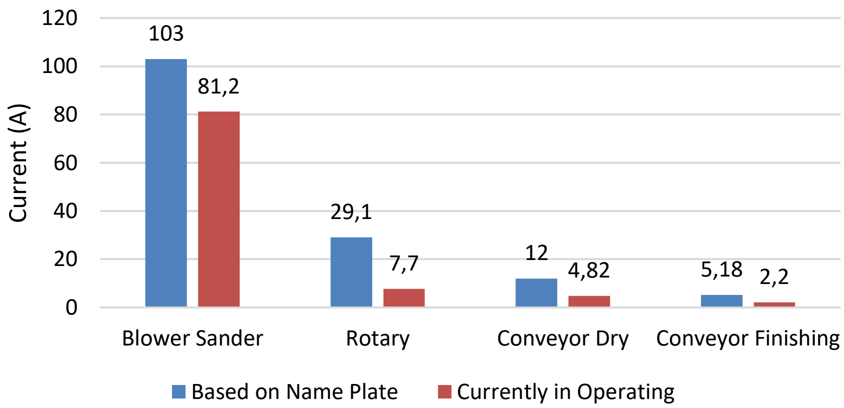

Figure 2. Flow relationship graph of the motor based on the name plate with the current condition motor

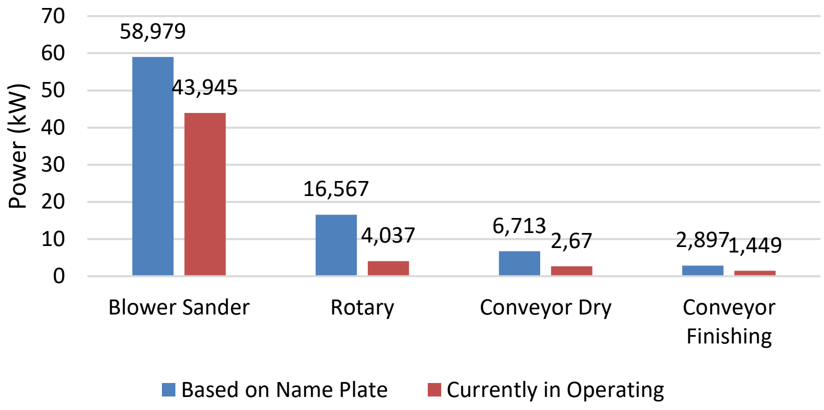

Figure 3. Relationship graph of the input power to the motor based on the name plate with the current condition motor

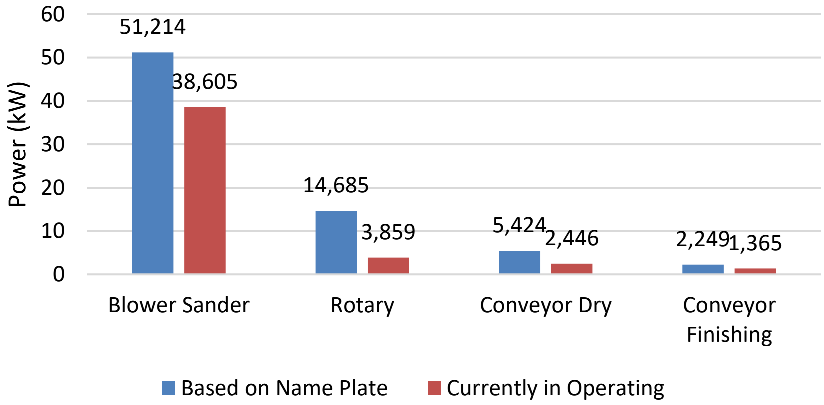

Figure 4. Graph of the relationship between the output power of the motor based on the name plate and the current motor condition

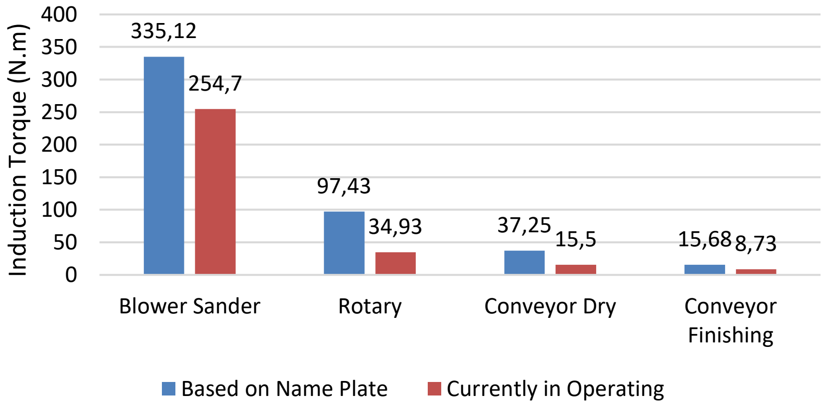

Figure 5. Relationship graph of induction torque on the motor based on the name plate with the current motor condition

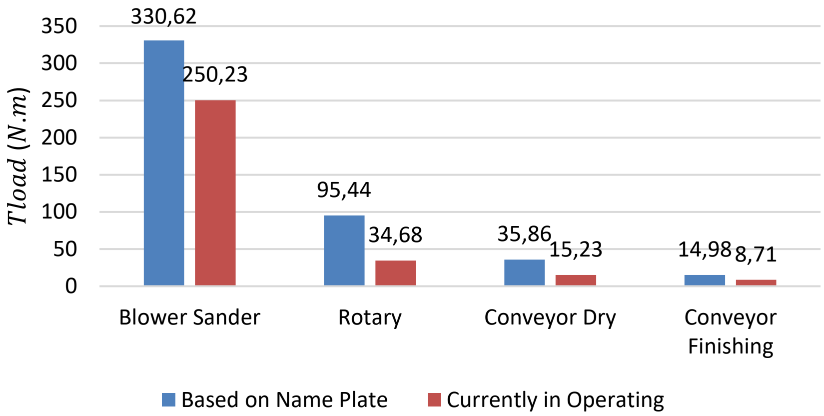

Figure 6. Graph of the relationship between the load torque on the motor based on the name plate and the current condition

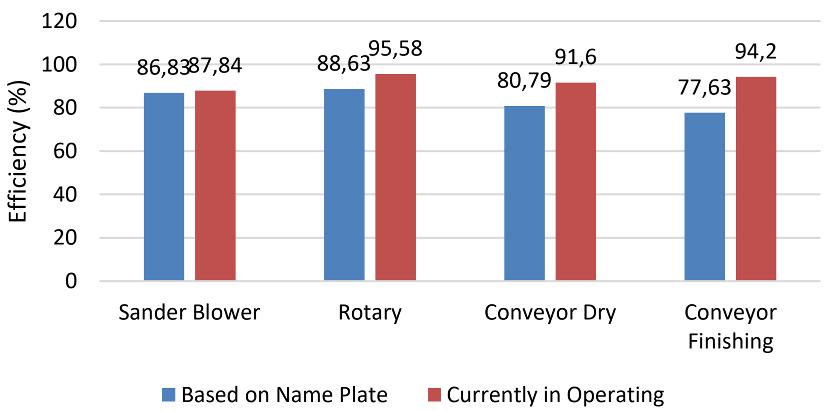

Figure 7. Graph of the relationship between the efficiency of the motor based on the name plate and the current motor condition