Implementation of Autonomous Maintenance on Maintenance of Three-Phase Slip Ring Induction Motor Used In Rubber Internal Motor Mixer

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The autonomous maintenance strategy involves the use of proactive maintenance techniques, to identify potential issues along with root causes within the motor. The maintenance strategy includes the development of degrees of maintenance actions to be done in the form of a schedule for routine maintenance tasks, such as cleaning, lubrication, and inspection, as well as the implementation of corrective maintenance procedures to address any identified issues. The effectiveness of the implemented strategies is evaluated through performance monitoring from prior and after the implementation of autonomous maintenance.

Overall, the results of this study demonstrate the importance of implementing effective maintenance strategies for the reliable operation of three-phase slip ring induction motors in rubber internal mixers. By implementing these strategies, it is possible to prolong the lifespan of the motor and ensure the smooth operation of the mixer.

Keywords: Three-Phase Induction Slip Ring Motor (3p-SR-IM), Rubber Internal Mixer (RIM), Autonomous Maintenance (AM), Maintenance Strategy, Proactive Maintenance

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1. INTRODUCTION

Due to its self-starting feature, a 3-phase slip ring induction motor (3p-SR-IM) is one of the frequently utilized electrical devices that transform electrical energy into mechanical energy for industrial purposes. An example of a winding rotor motor is the 3-phase induction motor (3P-IM) type 3p-SR-IM. It is utilized in applications that demand high torque, like cranes and elevators, due to several benefits such low initial current, strong starting torque, and better power factor. Compared to the squirrel-cage rotor, the rotor windings have more windings, a larger induced voltage, and less current. Slip rings connect the windings to external resistance, which aids in controlling a motor's torque or speed.

The use of 3p-SR-IM is prevalent in a variety of industries, including the tyre manufacturing industry. In the tyre manufacturing process, the rubber internal mixer is a crucial piece of equipment that is responsible for mixing and homogenizing the various raw materials used to produce tyres. The 3p-SR-IM is a key component of the mixer and its proper functioning is essential for the smooth operation of the equipment. As such, it is important to implement effective maintenance strategies to ensure the reliable performance of the motor and the efficient operation of the mixer. This study aims to investigate the implementation of autonomous maintenance strategies for 3p-SR-IMs used in rubber internal mixers in the tire manufacturing industry (Grossman, Richard F, 1997).

The primary and maybe most significant driving force behind the tire industry is maintenance (Raji A.O and Oke S.A,2019). Unfortunately, very little research is accessible on the optimization of the maintenance of 3p-SR-IMs that runs the machine process in terms of the Overall Equipment Effectiveness (OEE) of the systems, despite the fact that maintenance is vital (P.Tsaurohas, 2019).

2. LITERATURE REVIEW

2.1 Three-phase Induction Motor

Three-phase Induction Motors (3p-IMs) are electromechanical energy conversion devices which convert three-phase input electrical power into output mechanical power. There are basically 2 types of rotor, i.e., squirrel cage rotor where rotor poles adjust in accordance to stator poles so the resistance cannot be inserted, and wound rotor or slip ring motor where resistance can be inserted in the rotor. We focus on 3-phase slip ring induction motors (3p-SR-IMs) which are widely used in industrial machinery. In heavy load applications requiring a high initial torque, such as steel mills, lifts, cranes, hoists, line shafts, and other heavy mechanical workshops, the 3p-SR-IMs are used. **Fig. 2.1** shows the 3p-SR-IM of the rubber internal mixer motor that is being used in this study.

Figure 2. 1: Photograph of 3p-SR-IM of the Rubber Internal Mixer Motor maintained at the workshop - Farhan Mahaputra Rahman [PT. REMS]

2.1 Construction of 3p-SR-IMs

A 3p-SR-IM is an asynchronous motor because the rotor and stator poles are never moving at the same speed. The cores of the stator and rotor in the 3p-SR-IM (**Fig. 2.2**) feature laminated construction.

Similar to the stator of the squirrel cage induction motor, this motor's stator contains three-phase star or delta linked winding. A comparable 3-phase star linked winding is likewise carried by the rotor. The same number of poles are woven into the stator and rotor. Three insulated rings known as slip rings receive the rotor windings' open ends. These slide rings support the brushes and are installed on the motor shaft. With this configuration, external resistance can be added in series with each rotor phase to help with starting or speed control. Even the wound rotor short circuits on itself while operating normally, just like a squirrel cage rotor (Nam K.H, 2010). A 3p-SR-IM is schematically depicted in **Fig. 2.3**.

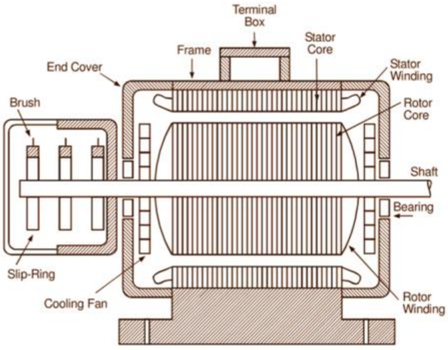

Figure 2. 2: Motor with Slip Ring Induction - Source: electricalworkbook.com

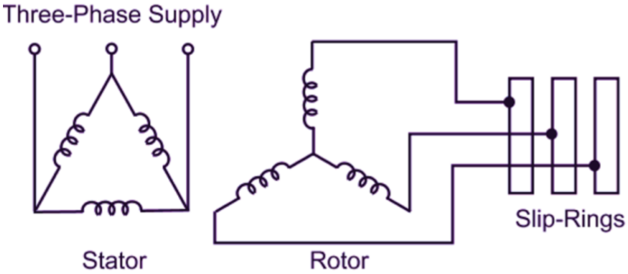

Figure 2. 3: A schematic illustration of 3p-SR-IM - Source: electricalworkbook.com

2.2 Stator Construction

The outer stationary component of the motor is represented by the stator in **Fig. 2.4**. The exterior cylindrical frame, the magnetic route, and a group of insulated electrical windings make up the device. In this study, the stator of the 3p-SR-IM is depicted in **Fig. 2.5**.

(i) **The external cylindrical structure:** It is constructed from cast iron, cast aluminum alloy, or welded sheet steel (Nam K.H 2010). This often features feet for the motor's foot mounting or a flange for the motor's other mounting options.

(ii) **The magnetic route:** It is made up of several slotted laminations of premium alloy steel that are supported by the external cylindrical stator frame (Nam K.H 2010). To lessen heating and eddy current losses, the magnetic channel is laminated.

(iii) **A set of insulated electrical windings:** Three sets of insulated electrical windings, one for each phase, are included in a 3p-stator IM's circuit, which is activated by a three-phase supply and has a 120° separation between the sets of coils (Nam K.H 2010). These coils are inserted into the laminated magnetic path's slots.

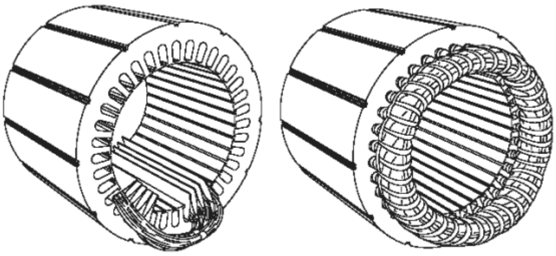

Fig 2. 4: Stator construction of 3p-SR-IM - Source: forumautomation.com and photograph

Fig 2.5. Stator construction of 3p-SR-IM - Source: forumautomation.com and photograph

2.3 Rotor Construction

The motor's rotating component is known as the rotor. It rotates coaxially with the stator and is positioned inside the stator bore. Similar to the stator, the rotor is constructed from a number of slotted, thin electromagnetic material (Special core steel) sheets that have been pressed together to create a cylinder. Through the use of paper and varnish, thin sheets are separated from one another. Slots are made up of an electrical circuit and a magnetic path is created by a cylinder-shaped electromagnetic material.

The rotor conductors of 3p-SR-IMs are insulated windings that are not shorted by end rings, but rather, the terminals of the windings are brought out to link them to three numbers of insulated slip rings that are fixed on the shaft, as illustrated in **Fig. 2.6**. Through brushes positioned on the slip rings, the rotor is electrically connected to the outside world. This type of motor is also known as a slip ring induction motor due to the presence of these slip rings.

Figure 2. 5: Photograph of Rotor construction of the studied 3p-SR-IM - Farhan Mahaputra Rahman (20-06-2022) [PT. REMS]

2.4 Operation

The electromagnetic induction theory of Faraday is the foundation of 3p-SR-IMs. A stator winding generates magnetic flux when it is energized by an AC supply. The rotor winding induces and produces a magnetic flux current according to Faraday's law of electromagnetic induction. This generated electromotive force (EMF) creates torque, allowing the rotor to turn.

However, because the created torque is not unidirectional, the phase difference between the voltage and current does not match the requirements to generate strong beginning torque. To increase a motor's phase difference, a large external resistance is connected to the circuit. Inductive reactance and the phase difference between current (I) and voltage (V) are thus decreased. As a result, the motor can produce a lot of starting torque because of this reduction. Below is a diagram of the slide ring induction motor from Figure **2.7**. (Saad N, 2019)

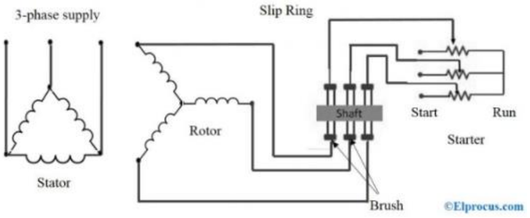

Figure 2. 6: 3p-SR-IM connection diagram - Source: elprocus.com

In a 3p-SR-IM, losses that result from converting this electrical energy into mechanical energy include the following (Kasim NI, Musa MA, Razali AR, Moh. Noor 2015):

- Windage and friction losses: 5% to 15%
- Losses from iron or core: 15 to 25%
- Losses from stator: 25% to 40%
- Losses from rotor: 15% to 25%
- Losses from stray loads: 10% to 20%

The range of full-load motor efficiency is roughly 85% to 97% (Kasim NI, Musa MA, Razali AR, Moh. Noor 2015)

3. METHODOLOGY

Maintenance on the defined 3p-SR-IM can be undertaken in 2 ways (see **Fig. 3.1**):

(i) Reactive maintenance, which involves fixing failures right away. Reactive maintenance will be performed in this study using abnormal or fault findings found in the service workshop. This includes the curative maintenance when a machine or an installation has broken down requiring to replace the equipment partially or in its entirety.

(ii) Proactive maintenance, in which the intervention of maintenance takes place before a breakdown occurs. The proactive maintenance carried out in this study will be taken from the faults that can be frequently observed and easily maintained by the technicians of the company. This includes the act of performing maintenance regularly scheduled to help prevent unexpected failures in the future.

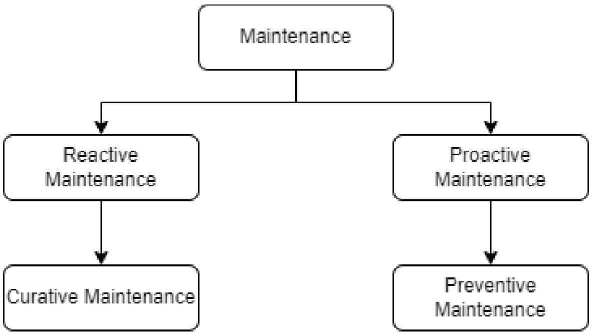

Figure 3. 1: Maintenance Action Flow Chart

In order to reap the benefits of performing AM, mapping of maintenance for RIM machinery utilizing 3p-SR-IM for the proactive maintenance in this research will use a step-by-step roadmap for a simple and practical AM implementation (M Tajiri M, Gotoh F, 1999).

The implementation of effective AM techniques involves seven steps, according to universal consensus (Mugwindiri, Kumbi, and Charles Mbohwa, 2013).

Step 1 - Boost Operator Awareness

Equipping operators with the information necessary to operate and maintain the equipment they are tasked with using is the first step in successfully implementing AM. Give them the understanding of how the components of the equipment work together so they are aware of which components require routine maintenance and which components require special attention for things like cleaning and lubrication.

Step 2 - Perform Initial Cleaning, Inspection, and Repairs

Operators should be able to inspect the equipment and identify any needs for cleaning and maintenance once they are familiar with the ins and outs of the machinery they are using. They must be able to recognize the equipment and the parts of it that require cleaning, tightening nuts and bolts, lubrication, and repair of wear and tear.

Step 3 - Eliminate Causes of Contamination

The operator must be aware of how to maintain the equipment once it has been cleaned and returned to its ideal working state. Getting rid of contamination sources is one technique to keep the equipment in good shape. Cleanliness and proper housekeeping at the workstation aid in preventing contamination and ensuring a secure working environment.

Step 4 - Capture Standards for Cleaning, Lubrication, and Inspection

Creating standards is the fourth step in the AM implementation process. With the assistance of operators, maintenance specialists, and engineers, these criteria should be customized for each asset.

Use checklist tools that may instruct operators on what to do and how to complete maintenance chores, and that can also alert operators when a work is approaching its due date. These standards are digitally recorded in electronic SOPs and maintenance procedures used in contemporary production environments.

Step 5 - Conduct Inspection and Monitoring

Conducting inspection and monitoring is advised to support good practices like AM. Operators can check their own equipment and offer details in the form of inspection reports with images on the equipment's present state and completed maintenance chores.

Step 6 - Standardized Visual Maintenance Management

Visual upkeep is really important. To assist operators in adhering to and reinforcing requirements for maintaining equipment and machinery, it is necessary to strive to develop a visual assistance system that supports the standards established at Step 4. Choose clear covers, detect flows, label open and closed valves, and create a tag system. Visual inspections at the beginning of each shift will go more quickly as a result.

Step 7 - Establish Continuous Improvement

Manufacturers will have access to a vast amount of data on how operators carry out duties as operators become more digitally connected. Manufacturers may learn which areas in productivity, training, workforce development, and content production have the greatest potential for continual improvement through the use of artificial intelligence tools, data analytics, and operator feedback.

4. RESULT

Analysis of Results Obtained After Implementation of AM

OEE parameter data collected prior to implementation of AM

Planned Time Available	32760 min
Planned Downtime	4680 min
Downtime Loss	7104 min
Net Available Time	Planned Time Available - Planned Downtime = 28080 min
Actual Operating Time	Net Available Time - Downtime Loss = 20976 min
Total Output	4195 mixed rubber
Rejected Output	176 rejected rubber
Final Availabelity A1	$\frac{Actual\ Operating\ Time}{Net\ Available\ Time} \times 100$
	$\frac{20976}{28080} \times 100 = 74{,}7\ \%$
Final Performance Effeciency P1	$\frac{Design\ Cycle\ Time\ \times\ Total\ Output}{Actual\ Operating\ Time}$
	$\frac{4.79\ \times\ 4195}{20976} \times 100 = 95{,}8\%$
Final Rate of Quality Q1	$\frac{Total\ Output\ -\ Defective\ Tires}{Total\ Output}$
	$\frac{4195 -\ 176}{4195} \times 100 = 95{,}8\%$
Final Overall Equipment Effectiveness OEE1	$A^1 \times P^1 \times Q^1 = 74{,}7\%\ x\ 95{,}8\%\ x\ 95{,}8\% = 68{,}5\%$

Comparison Analysis of Before and After Implementation

On the 3p-SR-IM of the RIM machine, a decrease in breakdowns was seen after the 7 steps of AM were implemented and carried out. The number of interventions made both before and after the improvements were put into place is shown below.

Table 4. 1: Improvements in Operation

Description	Units	Before AM Implementation	After AM Implementation	Change	Remarks
Downtime Loss	min	9463	7104	24.93%	Decrease
Actual Operating Time	min	18617	20976	12.67%	Increase
Total Output	tyre	3723	4195	12.68%	Increase
Rejected Output	tyre	201	176	12.44%	Decrease

Based on the data above, the comparison of values obtained before and after AM implementation. there can be seen improvements in which the downtime loss has decreased by 24.93% leading to more actual operating time by 12.67%, which means increase in the total output by 12.68% and rejected outputs decrease to 12.44%.

OEE results before and after the implementation of AM

Parameter	Before AM Implementation %	After AM Implementation %	Change	Remarks
Availability (A)	66.3	74.7	8.40	Increase
Quality (Q)	92.4	95.8	3.40	Increase
Performance (P)	94.6	95.8	1.20	Increase
OEE = A * Q * P	58	68.5	10.50	Increase

Consequently, an increase of 8.4% (from 66.30% to 74.7%) in the availability rate of the 3p-SR-IM on the RIM machine from before and after the implementation of AM (see **Table 4.6**). This element led to a notable 10.5% rise in OEE over the same period (from 58% to 68.5%), which had a direct impact on the RIM machine efficiency.

5. CONCLUSION

The seven steps of AM were applied, followed by PMO (Planned Maintenace Optimation), to achieve the main goal. By doing so, operators will be able to build the accountability to independently carry out proactive tasks connected to cleaning, organizing, and daily inspections of the workstation's important areas, ensuring that their RIM machine and 3p-SR-IM were in good operating order. Conclusion for the overall equipment effectiveness value of the 3p-SR-IM, it has increased from 58% to 68.5%. That is a 10.5% increase in OEE value. This is a significant raise in the OEE value, and has slightly exceeded the target of this study of 10% based on the implementation of AM. After implementing the ideas from this study (a) rubber for tire production saw an increase in actual operating time from 18617 minutes to 20976 minutes, i.e. 12.6% increase, (b) actual downtime loss from 9463 minutes to 7104 minutes, i.e. 24.93% decrease which is good, (c) total output from 3723 tires to 4195 tires, i.e. 12.68% increase, (d) and rejected output from 201 tires to 176 tires, i.e. 12.44% decrease which is good.

The identified problems and root causes of these failures have been noted in this study to create action plans for the proactive intervention actions before any failures occurring that involves, failure mode and effect analysis, and risk priority numbers. These will make it simple for operators and maintenance specialists to find a problem with the machines. The problems were addressed, and as a result of the outcomes, the business will think about applying this machine improvement technique to other machines.

A maintenance mapping procedure was created to tackle the reactive failures and proactive failures occurred by the 3p-SR-IM. This maintenance mapping was also made to create a proactive intervention before any proactive failures occur which assists in the implementation of AM for the RIM machine. All of this was accomplished by employing methods that directly address different types of issues and aid in the process' ongoing improvement. The effective application of AM paves the stage for the subsequent application of TPM principles (Suzuki T,1992), which will boost employee morale even more and make it easier to meet deadlines and satisfy market needs.

Based on the actions that has taken place, the analysis of the maintenance before and after implementation, it has shown that there were a significant increase of the OEE value by 10.5% which was compared by the recorded time of one month before the maintenance, and one month of implementation of AM after the maintenances were completed. This implementation displayed an improvement on the duration of operation of 3p-SR-IM before any breakdown occurs.

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