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Faults Analysis and Reliability Improvement of Pot Motor

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Abstract - *This paper describes the faults analysis and reliability improvement of pot motor. The pot motor is continuous running 24 hours in spinning machine to give high speed application for process of rayon production. The pot motor is placed under the most severe chemical conditions, exposed directly to splash of Glauber's salt ($Na2SO4.10H2O$) and sulphuric acid and others unknown factor affecting on pot motor. There is special design generator is used for power supply of pot motor. And pot motor should run for 24 hours its most important condition. By using capacitor bank, ceramic bearing, copper bar of rotor, change in diameter of stator winding, visual inspection by skilled person, etc. By applying all we get reliability improvement of pot motor.*

***Key Words*: Pot motor, faults analysis, power factor improvement, copper bar of rotor, ceramic bearing, testing and measurement, reliability etc.**

1. INTRODUCTION

The main objective of this study is to redesign a reliable scheme for pot motor. The pot motor is one of the parts of squirrel cage induction motor and the concept is same as squirrel cage induction motor. The cake of yarn is rotating in pot and this pot is mounted on the pot holder or shaft of pot motor. In the spinning machine there is required high speed rotating machine. So here by using special design of pot motor with high frequency and low voltage is used for supplying a power.

The pot motor is vertical axis motor which is placed under the spinning machine. The pot motor **should run for 24 hours** without any stop. In Indian Rayon there is near about **15000 nos. of pot motor** is used for process of rayon production. So that it's necessary to understand its construction, types of faults, environment, how to improve the reliability of pot motor and other affecting factors.

Figure No. 1: Pot motor

2. DESIGN OF POT MOTOR

According to design of pot motor is very special purpose. The pot motor is made in Japan. It is use since 1970. It means it is very old design of Japan. The design of pot motor is included in this table number 1 as follow,

Design of pot motor		
Sr. No.	Details	Remarks
1	Power	275 W
2	Voltage	150 V
3	Frequency	150 Hz
4	Stator slots	18
5	RPM	9000
6	Rotor slots	22
7	Air-gap	0.30 mm rad.
8	SWG	22

Table No. 1: Design of pot motor

According to table no. 1 the stator winding of pot motor is double layer type and in this lap winding is used. The conductor is dual coated with supper enameled type is used in the pot motor. The insulation class of this winding is F class-155° c.

The frame accommodating the electrical unit is made of special cast iron, having an extremely smooth surface which is specially coated which almost care f or excellent resistivity to acid, alkali, shock and impact. This special coating is incorporated into the unit shape of the equipment to provide it which sufficient durability even in operation under the most severs chemical condition.

The two deep groove ball bearings (6204, 6203) arranged with sufficient separation between them for minimizing the bearing load. The lubricant is draw in from the bottom of the spindle an allowed to run along the internal wall of the oil pipe for lubricating lower bearing returning to the oil tank.

3. FAULTS ANALYSIS

There are many reason of failure in pot motor. The pot motor often experience several types of faults. The failure of pot motor may shut down, even, entire industrial process resulting loss of production time and money. Hence is important to reduce any kind of failure of pot motor.

In faults analysis, when a fault has been identified, sufficient data is required for the operator for the best possible decision making on the correct course of action. If data is insufficient there remains the chance for wrong diagnosis of faults which leads to inappropriate replacement of components, and if the root of the problem is not identified properly, the replacement or any other action taken already will succumb to the same fate. The main functions of faults analysis follow as:

- To identified causes of failure
- To avoid the failure
- To reduce the maintenance
- To improve the reliability

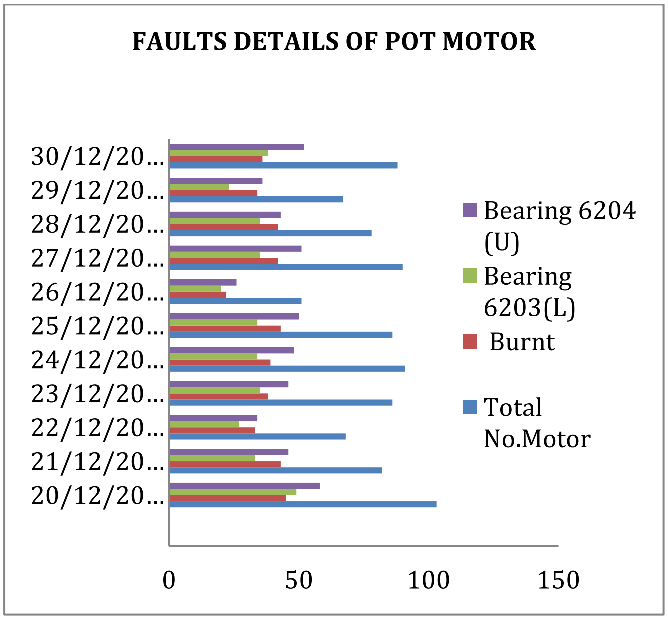

Chart No. 1: Faults details of pot motor

For faults analysis we need to study the types of faults has been occur in pot motor. The common faults of pot motor can be classified as stator (inter-turn) faults, rotor faults (broken rotor/end rings) and mechanical faults (bearing failure and air-gap eccentricity). Approximately 40-50 % of the faults of pot motor are stator related faults, 30-40 % is bearing faults, and 5-10 % is rotor faults.

3.1 STATOR WINDING FAULT

Stator of pot motor is subjected to various stresses such as mechanical, electrical, thermal, and environmental. Depending upon the severity of these stresses stator faults may occur.

This fault is due to failure of insulation of the stator winding. It is mainly termed as inter-turn short-circuit fault. Different types of stator winding faults are 1) short circuit between two turns of same phase—called turn-to-turn fault, 2) short circuit between two coils of same phase—called coil to coil fault, 3) short circuit between turns of two phases -called phase to phase fault, 4) short circuit between turns of all three phases, 5) short circuit between winding conductors and the stator core—called coil to ground fault, and 6) open-circuit fault when winding gets break.

3.2 SINGLE PHASING

In the three phases motor when one of the phases gets lost then the condition is known as single phasing. For single phasing faults motor winding get over heated, primarily due to flow of negative sequence current. If during the running condition of the motor single phasing faults occur motor continues to run due to the torque produced by the remaining two phases and this torque is produced as per the demand by the load-as a result healthy phases may be over loaded and hence over heated resulting in critical damage to the motor itself.

3.3 BROKEN ROTOR BAR

The pot motor consists of rotor bars and end rings. If one or more of the bars is partially cracked or completely broken, then the motor is said to have broken bar fault.

Also heavy end rings of rotor result in large centrifugal forces which may cause extra stresses on the rotor bars. Because of any of the reasons rotor bar may get damage which results in asymmetrical distribute on of rotor currents. Also, for such asymmetry or for long run of the motor if any of the rotors bar gets cracked overheating will occur in the cracked position which may lead to breaking of the bar.

3.4 BEARING DAMAGE

Two sets of bearings are placed at both the ends of the rotor of pot motor to support the rotating shaft. The bearing is 6204(Upper) and 6203(Lower). Bearing temperature should is another reason for bearing failure. Bearing temperature should not exceed certain levels at

rated condition. The factors that can causes the bearing temperature rise can be include winding temperature rise, motor operating speed, temperature distribution within motor, etc. Some source such as contamination, corrosion, improper lubrication, improper installation or brine ling reduces the bearing life.
Bearing corrosion is produced by the pressure of water, acids, deteriorated lubrication and even perspiration from careless handling during installation. Once the chemical reaction has advanced sufficiently, particles are worn-off resulting in the same abrasive action produced by produced by bearing contamination. Under and over-lubrication are also some other causes of bearing failure.

4. POWER FACTOR IMPROVEMENTS

The only possible source of excitation in pot motor is the stator input current. The pot motor is operating at a lagging power factor. The power factor is varying due to increasing load. The presence of air-gap between the stator and rotor of a pot motor greatly increases the reluctance of the magnetic circuit. Consequently, pot motor draws a large magnetizing current to produce the required flux in the air-gap.
At no load, pot motor draws a large magnetising current and small active component to meet the no load losses. Therefore, the pot motor takes a high no load current lagging the applied voltage by a large angle. Hence power factor of an induction motor on no load is low i.e. about 0.3 to 0.4 lagging.
At full load of pot motor the active component of current increases while the magnetizing component remains about the same. Consequently, the power factor of the pot motor is increased. However, because of the large value of magnetizing current, which is present regardless of load, the power factor of pot motor even at full load seldom exceeds 0.92 lagging.
The magnetizing current is the current that establishes the flux in the iron and is very necessary if the pot motor is going to operate. The magnetizing current does not actually contribute to the actual work output of the pot motor.

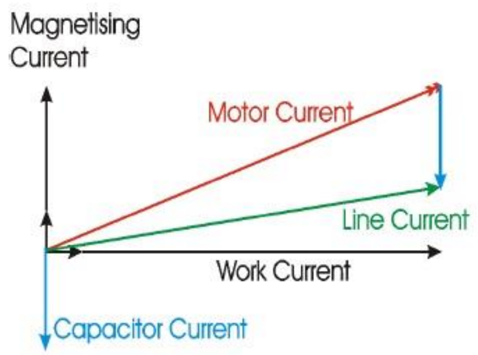

Figure No. 2: Current component pot motor

The magnetizing current and the leakage reactance can be considered passenger components of the current that will not affect the power draw by the motor, but will contribute to the power dissipated in the supply and distribution system.
In the interest of reducing the losses in the input of pot motor and distribution system power factor correction is added to neutralize a portion of the magnetizing current of the motor. There is many ways that this is metered, but the net result is that in order to reduce wasted energy in the distribution system, thus the industry will be encouraged to apply power factor correction.
There is special design generator is use for supplying power to pot motor. The generator is generated 500 V, 3125 KVA, 2500 KW, 140 Hz, and 1680 RPM. In one spinning machine have 144 pot motor is used. This type of 69 spinning machine is used. Presently the generator voltage is 490 V constant using AVR system and 132 Hz frequency is set. After generator the step down transformer is used for step down the voltage of 490 to 132 voltages.
The total number of 3 panels is supplying load to 69 spinning machine. The panel number 1 have 25 spinning machine is connected having load 760 KW, the panel number 2 have 12 spinning machine is connected having load 370 KW, the panel number 3 have 32 spinning machine is connected having load 970 KW. Total 69 spinning machine having a maximum load is 2100 KW. It means per spinning machine is maximum load is 30.43 KW. The average load demand of 24 hours is as per our measurement 49,120 KWh.
The main objective of power factor improvement is to decreasing losses and improving electrical load operation to a better efficiency. The power factor is improved by using capacitor banks. Presently there is 2 spinning machine is connected with 1 transformer having capacity is 150 KVA.
The only two spinning machine is connected due to large initial current flowing and several time no load condition is created causes of blackout or power outage. The drawback of this problem is increase in the distribution loss and reduction in the voltage level and result in poor reliability of pot motor.
The active component I_R, in phase with the supply voltage, is directly related to the output (and therefore to the part of electrical energy converted into energy of different types: mechanical energy, light energy, thermal energy.
The reactive component I_Q, in quadrature to the voltage, is used to generate the flow necessary for the conversion of powers through the electric or magnetic field and it is index of the transfer of energy between supply and load. Without this, there could be no net transfer of power, for example, magnetic coupling in the core of transformer or in the air gap of pot motor.

4.1 TESTING OF KW, P.F., KVA, KVAR

Spinning M/C # 24 and 25 on 150 KVA Transformer No. 12 3 KVAR × 3 Nos. Capacitor bank				
Without capacitors		With capacitors		Difference
Parameter	Testing	Parameter	Testing	
KW	60.78	KW	60.78	0
KVA	73.229	KVA	65.921	7.308
KVAR	33.91	KVAR	25.36	8.55
PF	0.830	PF	0.922	-0.092

Table no. 2 testing on transformer no. 12

Spinning M/C # 11 and 12 on 150 KVA Transformer No. 5 3 KVAR × 3 Nos. Capacitor bank				
Without capacitors		With capacitors		Difference
Parameter	Testing	Parameter	Testing	
KW	58.90	KW	58.90	0
KVA	69.71	KVA	63.265	6.445
KVAR	31.49	KVAR	22.94	8.55
PF	0.845	PF	0.931	-0.086

Table no. 3 testing on transformer no. 5

Spinning M/C # 31 and 32 on 150 KVA Transformer No.20 3 KVAR × 3 Nos. Capacitor bank				
Without capacitors		With capacitors		Difference
Parameter	Testing	Parameter	Testing	
KW	61.20	KW	61.20	0
KVA	76.781	KVA	67.549	9.232
KVAR	37.124	KVAR	28.574	8.55
PF	0.830	PF	0.906	-0.076

Table no. 4 testing on transformer no. 20

4.2 CALCULATION

Now we need to find how much energy saving is done by power factor improvement. So first of current of two spinning machine which is connected to transformer no. 12 current is given as,

$$\mathrm{I} = \frac{\mathrm{KW}}{\sqrt{3} \times \text{supply voltage} \times \text{power factor}}$$

$$I = \frac{60.78}{\sqrt{3} \times 132 \ \times 0.830} = 320.29\ A$$

Now calculate the current after improving power factor is given as

$$I = \frac{60.78}{\sqrt{3}\ \times 132 \ \times 0.922} = 288.33\ A$$

As we can see that equation there is current and KVA reduction on transformer which is given as,

320.29 - 288.33 = **31.96 A** and

73.229 – 65.921 = **7.308 KVA**

Same as transformer no. 5 have reduction of current and KVA is given as,

304.87 – 276.71 = **28.16 A** and

69.71 – 63.265 = **6.445 KVA**

And transformer no. 20 has reduction of current and KVA is given as,

322.50 – 295.45 = **27.05 A** and

76.781 – 67.549 = **9.232 KVA**

The power factor improvement is achieved by capacitor bank. The cost of capacitor bank is 1900 Rs/KVAR. And each capacitor bank is 3 KVAR capacities. Total cost of capacitor bank on each transformer two spinning machine is given as,

$$3 \times 3 \ \times 1900 \text{ Rs.} = 17100 \text{ Rs/ 2 spinnng m/c}$$

Avg. Saving in KVA/hr is given as,

= 7.66 KVA/ 2 spinning machine

Avg. Saving in KVA/day is given as,

$$= 7.66 \ \times 24 = 183.84\ KVA/day$$

According to saving in KVA there is also saving in steam consumption of high frequency turbine generator the data is collected from generator department of Indian rayon which is given as,

Generation details of plant			
Sr. No.	Parameter	UOM	Average
1	Avg. steam to HFTG	Avg. MT/day	518
2	Avg. power generation	Kwh	49258.26
3	Ratio	Kg/Kwh	10.52
Considering P.F. 0.80		Kg/KVAh	8.42

Table No. 5: Generation details of plant

Now Avg. steam saving/day is

$$= 183.84 \times 8.42 = 1547.93\ kg/day$$

Consider if steam cost is Rs 0.85 kg then return of investment (ROI) or payback is given as,

$$= 17100 \div 1547.93 \div 0.85 = 13 \text{ day}$$

Losses caused by poor power factor are due to reactive current flowing in the system. These are watt-related charges and can be eliminated through power factor correction. Power loss in distribution system is calculated by squaring the current and multiplying it by the circuit resistance. To calculate loss reduction is given as,

$$\%\ \text{reduction losses} = 100 - 100 \times \left(\frac{\text{old p.f.}}{\text{new p.f.}}\right)^2$$

$$= 100 - 100 \times \left(\frac{0.835}{0.919}\right)^2$$

$$= \mathbf{17.44\ \%}$$

It means total losses in secondary of transformer where pot motor input is connected so total reduction in current will reduce voltage drop with improving reliability of pot motor. by improving power factor of pot motor there is **improving** the **efficiency** of pot motor.

5. CERAMIC BEARING

A magnetic flux of alternating magnitude will be generated if the pot motor is not centred in the stator of if the slots of the stator windings are not symmetrical. This circulating flux generated in the stator gives a rotor flux alternating between symmetrical and asymmetrical. The flux changes induce a shaft voltage which has the same frequency as the supply frequency, or a multiple of it. The axial shaft voltage results in a low frequency, circulating current that flows through the bearings.

There is a common mode disturbance, causing current asymmetry between the three phase in the stator windings. The current sum over the stator circumference is not zero high frequency flux variation is surrounding the shaft, creating a high frequency shaft voltage. Therefore, there is a risk for an axially flowing current through the rotor, which runs through one bearing and back through the other.

Various method exist for correcting motor performance such as correcting the cable shielding, improving the grounding of the motor housing, using single phase filters, installing an electromagnetic shield between the stator and rotor, grounding the rotor, or using a non-conducting coupling.

Figure No. 3: Ceramic bearing

However, one of the simplest methods is to insulate the bearings and disrupt the current flow. This can be done by installing an insulated shield in the bearing housing bore or by insulating the bearing itself or by use of **ceramic bearing**.

The ceramic bearing are made entirely of ceramic material and are superior to common steel insert bearing in many ways, ceramic is the perfect material for any application seeking to achieve higher rpm, reduce overall weight or for extremely harsh environment where high temperature and corrosive substances are present.

Ceramic materials commonly used for bearings are Silicon Nitride (Si3N4), Zirconium Oxide (ZrO2), Alumina Oxide (Al2O3) or Silicon Carbide (Sic).

Because ceramic is a glass like surface it has an extremely low coefficient of friction and is ideal for application seeking to reduce friction. Ceramic balls require less lubricant and have greater hardness than steel balls which will contribute to increased bearing life. Thermal properties are better than steel balls resulting in less heat generation at high speeds.

Figure No. 3: Glauber's salt on pot motor

The pot motor is under the most severe chemical conditions, exposed directly to splash of **Glauber's salt** ($Na_2SO_4.10H_2O$) and **sulphuric acid** and others unknown factor affecting on pot motor.
Full ceramic insert bearing can continue to operate under extremely high temperature and are capable of operating up to 1800 degree F. Ceramic is much lighter than steel and many bearing are1/3 the weight of a comparable steel bearing. Full ceramic insert bearing are highly corrosion resistant and will stand up to most common acids, they will not corrode in exposure to water or salt water. And finally full ceramic insert bearings are non-conductive.

6. COPPER BAR OF ROTOR

The magnetic material plays a significant role in the improvement of the motor performance. Respects to this goal, its main features are the magnetic permeability and the specific loss. It is well known that incorporation of copper for the rotor bars and end rings in place of aluminium would result in attractive improvements in motor energy efficiency.
Die casting is widely recognized as a low cost rotor cage manufacturing process. For these reason, die casting has become the fabrication method of choice and aluminium the conductor of choice in all but the largest frame motors.
The melting point for aluminium alloys is in the 670° C range and the material used for the rotor's die casting mould is not highly stressed at these temperatures. Die life can be in the hundreds of thousands of rotors depending on die complexity.
Most commonly used method to manufacture rotors with copper conductors is referred to as "welded assembly construction". such fabrication involves intensive hand labour and therefore is expensive.
Presently only small numbers of very large motors utilize copper in the rotors by this mechanical fabrication. The additional manufacturing challenges are increased temperature and pressures required to die cast copper: it melts at 1083° C. Although copper die cast rotor construction is a much newer technology.
The integrity and reliability of copper die cast is just as good as in aluminium die cast. The primary reason copper die cast rotors are not common place yet is because it requires specialized equipment and investment.
Electrical steel 5350H represents a very good compromise between specific loss and permeability. In fact, frequently better magnetic materials from the losses point of view have worse permeability. As a consequence, the increases of magnetizing current and corresponding joule losses reduce the benefit of the lower iron losses. The **electrical steel 5350H** can be define "**premium steel**" because combines **low specific losses** 3.5 W/kg with **high permeability** 1.2 T.
We study the research paper of copper bar rotor which tested on 3 KW squirrel cage induction motors by CSA test results. By this test it is conclude that the substitution of copper for aluminium directly achieved 75% of the total saving in rotor losses and was indirectly involved in saving the other 25% in stator resistance losses. Rotor I^2R losses were reduced by 46% and the efficiency resulted 2.1% is higher.
By comparison of this result to pot motor have reducing the I^2R losses and also it's was indirectly reducing the stator resistance losses. by used of die cast copper bar in rotor we can improve the efficiency and reliable operation of pot motor.

3. CONCLUSIONS

After study, measurement and faults analysis we conclude that we get improvement in performance of pot motor by applying power factor improvement, copper bar of rotor, ceramic bearing. We can use core tester for rejecting damaged stator. By power factor correction we get reduction in losses, voltage drop, heating losses and increasing the KVA demand. Overall we get reliability improvement of pot motor.

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