Nano Alumina Coated DC Shunt Motor

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Abstract - This research deals with the mixing of enamel with Alumina nano filler and coating of this enamel to the windings of the DC shunt motor. This paper deals with the analysis of the performance of normal and nano coated DC shunt motor. The efficiency and thermal withstanding capacity of the motor was improved by adding nano fillers to the enamel used for the coating of the windings of the motor and hence the DC shunt motor can be called as Nano coated DC shunt motor or Energy efficient DC shunt motor or High efficient DC shunt motor. This was one of the applications of nano technology in electrical engineering. Similar works were conducted previously on single phase and three phase induction motors by coating the windings of the motors with alumina and silica nano particles. This kind of work can be extended for different types of motors by coating with various nano fillers such as TiO_2, ZnO, and ZrO_2 and also with the mixture of nano composites for both AC and DC motors.

Key words – DC motor, Nano fillers, Load test, Efficiency.

I. INTRODUCTION

Nano filler added insulating materials were used in the generation, transmission, distribution and utilization of electrical energy and hence this division of engineering were collectively called as Nano Electrical Energy Systems Engineering. The salient parts of a DC motor were yoke, main field system, brushes, armatures and commutator. DC motors work on the principle based on Faraday's law of electromagnetic induction and Lenz's law. DC motors were widely classified into shunt motor, series motor and compound motor. Organic varnishes and enamel were widely used in the Insulation system of electrical machines for impregnation and finishing applications. Impregnating and finishing agents offer several advantages, such as improved mechanical bonding to the winding wire, improved dielectric properties, improved thermal conductivity and protection to the winding against moisture and chemically corrosive environment. Al_2O_3 nano fillers have better electrical, thermal, mechanical and physical properties.

II. SYNTHESISATION AND CHARACTERIZATION OF ALUMINA (AL_2O_3) NANO FILLER

The synthesis and study of nano particles, has become a major interdisciplinary area of research over the past 10 years. The size, morphology as well as the properties of nano particles basically depends on the methods of preparation. All the processes can be broadly divided into two processes, physical methods and chemical methods. Al_2O_3 was one of the most commonly encountered substances in both daily life and in electronics manufacturing and Al_2O_3 was the naturally occurring oxide, the most cost effective and widely used material in the family of engineering ceramics. The raw materials from which this high performance technical grade ceramic was made were readily available and reasonably priced, resulting in good value for the cost in fabricated Al_2O_3 shapes. With an excellent combination of properties and an attractive price, it was no surprise that fine grain technical grade has a very wide range of applications. Figure 1 shows the Structure of Al_2O_3. The general properties of Al_2O_3 are,

- Hard, wear-resistant
- Excellent dielectric properties from DC to GHz frequencies
- Resists strong acid and alkali attack at elevated temperatures
- Good thermal conductivity
- Excellent size and shape capability
- High strength and stiffness

Available in purity ranges from 94%, an easily metallizable composition, to 99.5% for the most demanding high temperature applications.

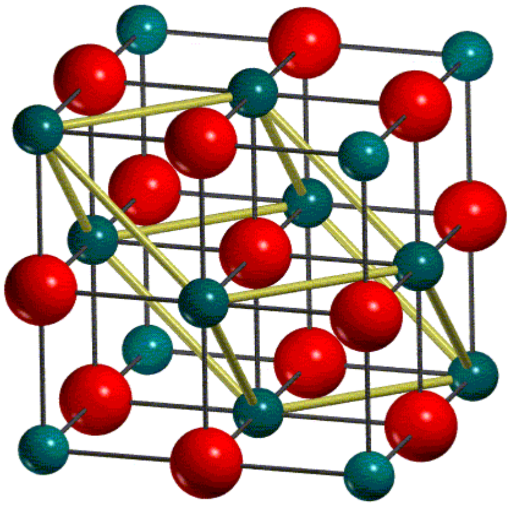

Figure 1 Structure of Al_2O_3

2.1 Properties of Alumina

Al_2O_3 which has excellent mechanical property can be understood from the following Table 1.

Property	Value with Units
Tensile strength	200 - 250 N/mm^2
Bending strength	200 - 600 N/mm^2
Compressive strength	1900 - 2000 N/mm^2
Young's modulus	3.8 x 10^{5}N/mm^2

Table 1 Mechanical properties of Al_2O_3

Thermal properties like Conductivity, Specific heat, Thermal shock resistance of the Al_2O_3 as nano filler is listed in the table which shows that both have good thermal conductivity. In the window building industry "thermal conductivity" is expressed as the U-Factor, which measures the rate of heat transfer and tells you how well the window insulates. Al_2O_3 has excellent thermal property can be understood from the following table. Table 2 shows the thermal properties of Al_2O_3.

Property	Value with Units
Specific heat 100°C	930 J/kg.K
Thermal conductivity at 20°C	40 W/m.K
Thermal shock resistance	200°C

Table 2 Thermal properties of Al_2O_3

Various electrical parameters like Dielectric Strength, loss factor and resistivity are listed in the table for pure Aluminium tri oxide. Table 3 shows the Electrical properties of Al_2O_3.

Property	Value with Units
Resistivity at 20°C	>10^{14} ohm.cm
Dielectric constant at 20°C	9.51 GHz
Dielectric rigidity at 50Hz	30 kV/mm

Table 3 Electrical properties of Al_2O_3

2.2 Synthesis of Nano particles - Ball Mill Method

Ball mill was an efficient tool for grinding many materials into fine powder. The ball mill was used to grind many kinds of mine and other materials. It was widely used in chemical industry. There are two ways of grinding: dry process and the wet process. The ball mill was key equipment for regrinding. It was widely used for manufacture of the cement, the silicate product glass and ceramics. Aluminium trioxide nano material was synthesized by using ball mill. Figure 2 shows the image of Ball mill.

Figure 2 Ball mill

- ❖ The pulverise tie 6 planetary mono mill was universally applicable for quick dry or wet grinding of inorganic and organic samples for analysis, quality control, materials.
- ❖ The sample material was crushed and disintegrated in a grinding bowl by grinding balls.
- ❖ The grinding balls and the material in the grinding bowl were acted upon by the centrifugal forces due to the rotation of the grinding bowl about its own axis and due to the rotating supporting disc.
- ❖ As a frictional effect, the grinding balls running along the inner wall of the grinding bowl, and impact effect, the balls impacting against the opposite wall of the grinding bowl.
- ❖ Alumina nano sample was prepared by Ball mill method. According to literature survey 40gms of Alumina micro powder was grinded for the time period of 36 hours. For every 15mins of interval ball mill was stopped to eliminate the heat produced during grinding. After the milling process the alumina was given for SEM analysis.

2.3 Characterization of Nano particles – SEM Analysis

Al_2O_3 particles were subjected to scanning electron microscopy and studies to analyze the surface and structure of the nano particles. The principle of scanning electron microscopy and the obtained SEM pictures and their interpretations were explained in this paper. Scanning electron microscopy uses a focused high energy electron beam to image the surface of a variety of samples and collect information on morphology and elemental composition. A scanning electron microscope was a highly versatile tool and can be used to study biological specimens, geological materials, nano particles, circuit boards, and many other sample types. A SEM consists of an electron gun, focusing lenses, stage or specimen holder, and several types of detectors. The electron gun contains a heated metallic filament, usually tungsten, which provides the source of electrons. These electrons were accelerated toward an anode plate and then focused by condenser lenses and an objective lens. A deflector coil causes the focused electron beam to be scanned across the surface in a raster pattern. Figure 3 shows the image of SEM. There were two types of electron microscope – the scanning electron microscope (SEM) and the scanning transmission electron microscope (STEM). The samples must be conducting (in order to accelerate electrons into the sample) and hence a biological sample must have a gold layer deposited on its surface if it is to be investigated by SEM or STEM. In the STEM, the sample was a very thin specimen and contrast within the image was due to the spatial variations in intensity of the transmitted electron beam through the specimen, as the beam was scanned over the specimen.

Figure 3 Hitachi SU- 1510 Scanning Electron Microscope

In SEM, the image may be produced in a number of ways from variations in the intensity of secondary electrons back–scattered from the specimen through to X-ray emission produced by inelastic collisions of the primary beam with bound electrons in the specimen. The idea that gave rise to the electron microscope is that, just as light is refracted and focused by an optical lens, the electron, due to its charge, will produced Cambridge Instruments Ltd. The electrons were emitted by an incandescent cathode source, accelerated towards more positive grids through either electrostatic or magnetic field lens onto an object. The specimen was supported on a very thin film to minimize the scattering of the electrons as they pass through the sample. Depending on the thickness and composition of the object, the electron beam experiences different attenuation as a function of position. The beam travels through two more lenses before being imaged onto a fluorescent screen (in original models) or photographic plate or directly onto a scintillator placed on the face of a photomultiplier tube or a CCD device. A scintillator was a semi-transparent material, which emits a flash of light when a charged particle traverses it. The spatial resolution of this type of microscope was determined by the wavelength associated with the electrons and this wavelength may be 100,000 times smaller than optical wavelengths at the typical accelerating voltages used in electron microscopy. Once the micro particles of Al_2o_3 were converted into nano particles with the help of ball mill, it was subjected to SEM. Scanning electron microscope (SEM) has been used to augment the particle size of nano composite.SEM image of alumina on both before and after milling process were shown in Figure 4 and 5 respectively. The micro size particles of Al_2O_3 were in the range from 40 to 100 µm size. Figure 4 shows the SEM image of Al_2O_3 at 10 µm.

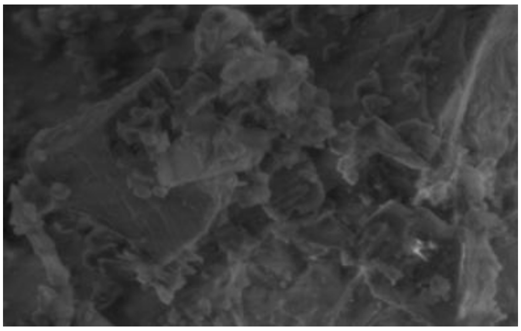

Figure 4 SEM analysis of Al_2O_3 at 10 µm

The micro size particles were converted into nano size with the help of Ball Mill. From the analyzed SEM image the particles are in the form of nano metric range varies for one area to other. The sizes of the particles are in the range from 180 to 250 nm size. Figure 5 shows the SEM analysis of Al_2O_3 at 5µm.

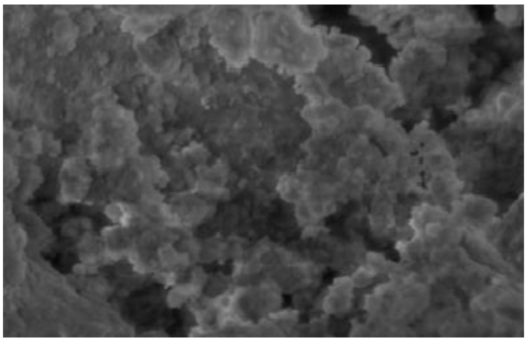

Figure 5 SEM analysis of Al_2O_3 at 5µm

2.4 Mixing of Enamel with Nano particles - Ultrasonic Vibration

The prepared nano particles were mixed with standard (Elmo Luft 1A-FD) enamel by using ultrasonic vibrators shown in figure 6. The ultrasonic vibration was a mechanical process. During the operation of ultrasonic vibrator the mechanical energy was generated. This mechanical energy in the vibrator was in terms of vibration. This mechanical vibration was used to mix the nano particles of Al_2O_3 to the pure enamel.

Figure 6 Ultrasonic vibrator

The frequency range of the ultrasonic vibrator was 20-40 KHz. This mixing process was conducted up to one hour. For a single motor 6 gm of nano filler was added to the 150 ml of pure enamel. The Alumina filler was mixed with enamel at appropriate proportion and coated on the copper winding of the motors. This nano filler mixed enamel coated windings are wounded on the motor.

III. PERFORMANCE ANALYSIS OF DC SHUNT MOTOR

The field coil and the armature windings were connected in shunt or parallel across the power source. The armature winding consists of relatively few turns of heavy gauge wire. The voltage across two windings was the same but the armature draws considerably more current than the field coil. Torque was caused by the interaction of the current caring armature winding with the magnetic field produced by the field coil. If the DC line voltage was constant, the armature voltage and the field strength will be constant. The speed regulation was quite good; the speed was a function of armature current and was not precisely constant. As the armature rotates within the magnetic field, an EMF was induced in its wining. This EMF was in the direction opposite to the source EMF and was called the counter EMF (CEMF), which varies with rotational speed. Finally, the current flow through the Armature winding was a result of the difference between source EMF and CEMF. When the load increases, the motor tends to slow down and less CEMF was induced, which in turn increases the armature current providing more torque for the increased load. Motor speed was increased by inserting resistance into the field coil circuit, which weakens the magnetic field. Table 1 shows the rating of the DC shunt motor used for this research.

Table 2 Specifications of the motor

Rated Voltage	230 V
Rated Current	2.5 A
Rated Speed	1500 rpm
Insulation Type	Class A
Rating of the Motor	0.5 HP

3.1 Construction, Working and Losses of DC Shunt Motor

The construction of DC shunt motor was quite similar to any other types of DC motor. The main difference lies in the connection of field winding with armature. In this type of motor field coil was connected in parallel with the armature.

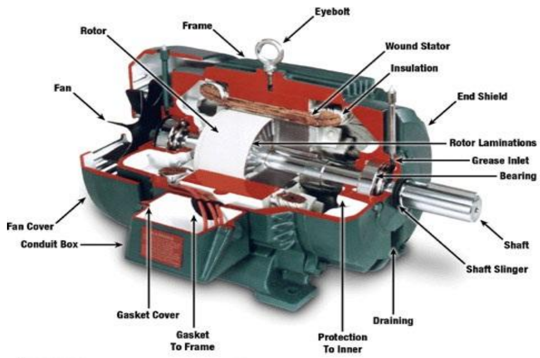

Figure 7 constrution of DC shunt motor

The different parts of a DC motor were

1.Stator

a)Yoke

b)Poles

c)Pole shoe

d)Field winding

2.Rotor

a)Armature winding

b)Armature slots

c)Comutator

d)Carbon brushes

e)Shaft

The field coil of a DC shunt motor was called stator which was the static part of the motor. This field or shunt winding was made of fine coils of large number of turns. Since shunt winding was not a thick gauge winding so it cannot carry high value of current. DC power was directly supplied to the stator. Armature of the DC shunt motor was known as the rotor. This was the rotating part of the shunt motor and this part was free to move. Shaft was connected to the rotor and the mechanical load was coupled with the the shaft. The armature was parallel with the voltage source but this winding was made up with thick gauge wire of low resistance. So, very high amount of current passes through the rotor circuit. The commutator provides the current from field winding to the rotating armature with the help of brush gear arrangement. Dc motor working based on Faraday`s law of electromagnetic induction principle.

When electric voltage was applied to the DC shunt motor, due to higher resistance of the shunt winding, it draws very low current. The higher number of turns of the shunt winding helps in generating a high magnetic field. The armature draws high current, thus also generating a high magnetic field. The motor starts rotating as the magnetic field of the armature and shunt winding interact. As the magnetic field grows stronger, rotational torque will increase, thus resulting in an increase of rotational speed of the motor. A shunt dc motor has a feedback mechanism which controls its speed. As the armature rotating in a magnetic field, it induces electricity. This EMF was generated in a reverse direction, thus limiting the armature current. So the current through the armature was decreased and speed of the motor was self regulated. The shunt winding cannot bear high current at starting like a series motor because of its fine wire build, so shunt motor were used to handle small shaft loads that only need low torque initially. In DC motor, there will be copper losses ($I^2_a r_a$ and $I^2_f R_f = VI_f$) in armature and field circuit. The armature copper loss was variable and depends upon degree of loading of the machine. For a shunt machine, the field copper loss will be constant if field resistance was not varied. Rotor body was made of iron with slots in which armature conductors were placed. Therefore when armature rotates in presence of field produced by stator field coil, eddy current and hysteresis losses were bound to occur on the rotor body made of iron. The sum of eddy current and hysteresis losses was called the core loss or iron loss. To reduce core loss, circular varnished and slotted laminations or stamping were used to fabricate the armature. The value of the core loss will depend on the strength of the field and the armature speed. Apart from these there will be power loss due to friction occurring at the bearing & shaft and air friction (windage loss) due to rotation of the armature. The major losses occurring in a DC machine were summarized as

1. Field copper loss: It is power loss in the field circuit and equal to $I^2_f R_f = VI_f$

   During the course of loading if field circuit resistance is not varied, field copper loss remains constant.

2. Armature copper loss: It is power loss in the armature circuit and equal to $I^2_a r_a$. Since the value of armature current is decided by the load, armature copper loss becomes a function of time.

3. Core loss: It is the sum of eddy current and hysteresis loss and occurs mainly in the rotor iron parts of armature. With constant field current and if speed does not vary much with loading, core loss may be assumed to be constant.

4. Mechanical loss: It is the sum of bearing friction loss and the windage loss (friction loss due to armature rotation in air). For practically constant speed operation, this loss too, may be assumed to be constant.

Normally the DC shunt motor was coated with pure enamel. There were different types of insulation such as Class Y, Class A and Class E. This type of insulation was used in the motor based on the temperature level. In this motor Class A insulation was used.

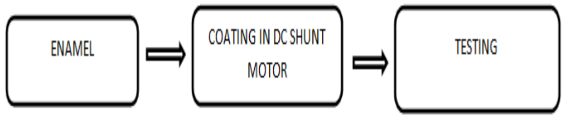

Figure 8 Block Diagram of normal DC shunt motor

The enamel was mixed with nano composites and it was coated in the stator winding and the insulation paper. The procedure was shown in the Figure 8 and 9.

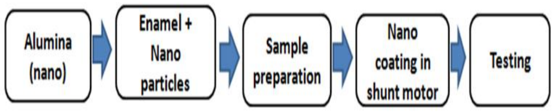

Figure 9 Block diagram of nano coated DC shunt motor

Alumina filler was mixed with enamel at appropriate proportion and coated on the copper winding of the shunt motor, this material was added based on the analysis made earlier, thus this enamel was coated on the windings of the motor and then they were air dried. Load test and temperature test were conducted in this motor to find the efficiency and thermal withstanding capacity of the motor.

3.2 LOAD TEST ON DC SHUNT MOTOR

Load test was conducted on DC shunt motor to find the efficiency and torques of the motor. It was conducted as per the steps explained below.

1. Connections were made as per the circuit diagram as shown in figure 10 and 11.
2. After checking the no load condition, and minimum field rheostat position, DPST switch was closed and starter resistance was gradually removed.
3. The motor was brought to its rated speed by adjusting the field rheostat.
4. Ammeter, Voltmeter readings, speed and spring balance readings were noted under no load condition.
5. The load was then added to the motor gradually and for each load, voltmeter, ammeter, spring balance readings and speed of the motor were noted.
6. The motor was then brought to no load condition and field rheostat to minimum position, then DPST switch was opened.

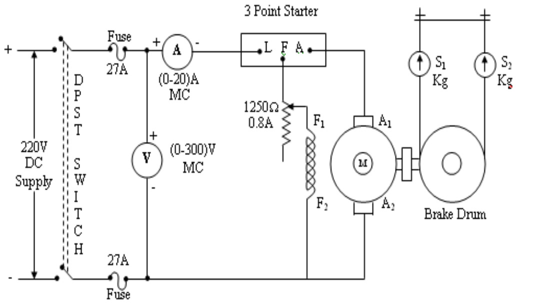

Figure 10 Circuit Diagram for load test on DC shunt motor

Figure 11 Circuit arrangements for Load test on DC shunt motor

Before conducting the load test on DC shunt motor, the necessary precautions were followed as shown below.

1. DC shunt motor should be started and stopped under no load condition.
2. Field rheostat should be kept in the minimum position.
3. Brake drum should be cooled with water when it was under load.

The output power, torques and efficiency were calculated by the formulae shown below.

1. Torque (T) = $(F_1 \sim F_2)*9.81*r$ Nm (1)

   r = Radius of the brake drum (m)
2. Output power (P_{out}) = $2\pi NT/60$ W (2)

   N = Speed in rpm.
3. Input power(P_{in})=$V(I_f + I_a)$ W (3)

   I_f = Field current

   I_a = Armature current
4. Efficiency = P_{out} / P_{in} % (4)

Table 3 Load test on DC shunt motor before nano coating

S. No	Voltage (V)	Current (A)		Spring Balance Reading		Input Power in Watts	Output Power in Watts	Torque in N-m	Efficiency in %
		Armature Current (A)	Field Current (A)	S_1	S_2				
1	220	0.3	0.38	0	0	149.6	0	0	0
2	219	0.8	0.38	2	3	258.42	113.75	0.765	44.0
3	218	1	0.38	2	4	300.84	208.28	1.530	69.2
4	217	1.2	0.38	3	5	342.86	195.46	1.530	57.0
5	217	1.8	0.38	3	6	473.06	273.97	2.295	57.91
6	216	2	0.38	4	8	514.08	301.21	3.060	58.59

Table 4 Load test on DC shunt motor after nano coating

S. No	Voltage (V)	Current (A)		Spring Balance Reading		Input Power in Watts	Output Power in Watts	Torque in N-m	Efficiency in %
		Armature Current (A)	Field Current (A)	S_1	S_2				
1	220	0.3	0.34	0	0	140.8	0	00	0
2	219	0.8	0.34	2	3	249.66	114.55	0.765	45.88
3	218	1.1	0.34	2	4.2	313.92	232.36	1.681	74.01
4	218	1.3	0.34	3	5.2	357.52	216.52	1.681	60.56
5	217	1.6	0.34	3	5.8	420.98	256.83	2.140	61.0
6	217	2.1	0.34	3	7	529.19	314.0	3.057	61.6

3.3 TEMPERATURE TEST

The temperature test is conducted on the normal DC shunt motor and Nano coated DC shunt motor to test the temperature level at various time periods in running condition.

- Initially, the thermometer reading was noted.
- Load was applied to the shunt motor.
- Thermometer was placed on the field winding of the normal DC shunt motor and Nano coated DC shunt motor.
- Temperature readings are noted at various time intervals.

Table 5 shows the comparison of temperature of the normal DC shunt motor and the nano coated DC shunt motor. Figure 12 shows comparison of temperature of normal and nano coated DC shunt motor.

Table 5 Comparison of temperature of normal and nano coated DC shunt motor

S. No	Time in Minutes	Temperature of Normal Motor in ^{o}C	Temperature of Nano Coated Motor in ^{0}C
1	2	44	43
2	6	48	44
3	10	49	44.5
4	14	50	45.5
5	18	51	46
6	22	52.5	47
7	26	54	48
8	30	56	49

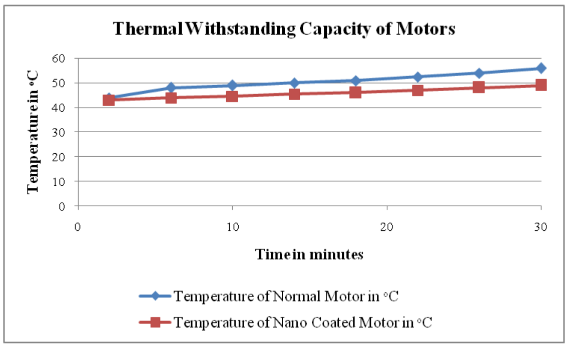

Figure 12 Comparison of temperature of normal and nano coated DC shunt motor

3.4 Advantages of Nano Coated Motor

- Higher thermal withstand capacity.
- Reduced power.
- Higher Efficiency.
- Increased Life time.

3.5 Applications of Nano Coated Motor

- Centrifugal pumps
- Blowers
- Fans
- Machine tools
- Lathes

IV. CONCLUSION

The efficiency of the DC shunt motor was increased by adding nano filler of Al_2O_3 to the enamel used as a coating for the windings of the DC shunt motor. The addition of nano fillers to the enamel has increased the temperature withstanding capacity of the DC shunt motor. Hence the life time of the motor will be increased. In this paper, the efficiency of the dc shunt motor was improved with the help of nano filler material. This nano filler was also used to reduce the maximum temperature rise of the dc shunt motor. Insulation was used in all the electrical motors and generator. This concept was applicable for all electrical machines. If 1% of efficiency was improved in the entire electrical machines, it will save 200MW in all over India. SiO_2 and TiO_2 nano fillers are used in the single phase induction motor and three phase squirrel cage induction motor as an insulating material. Al_2O_3 was used as nano filler in DC shunt motor. In future various nano fillers can be used with the enamel to improve the performance and life time of the several motors.

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