AERO DESIGN CHALLENGE 2021

BRUSHLESS DC MOTOR

FABRICATION REPORT

ADC20210114 – YODDHA

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2021 SAE AERO DESIGN CHALLENGE

STATEMENT OF COMPILANCE

CERTIFICATE OF QUALIFICATION

TEAM NAME	YODDHA
TEAM ID	20210114
COLLEGE	Shri G.S. Institute Of Technology And Science, Indore
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As Faculty Advisor, I certify that the registered team members are enrolled in collegiate courses. This team has designed, constructed and modified the radio controlled airplane they use for the SAE Aero Design Challenge 2020 competition, without direct assistance from professional engineers, R/C model experts or pilots, or related professionals.

(Dr G. Thakar)

Signature of Faculty Advisor

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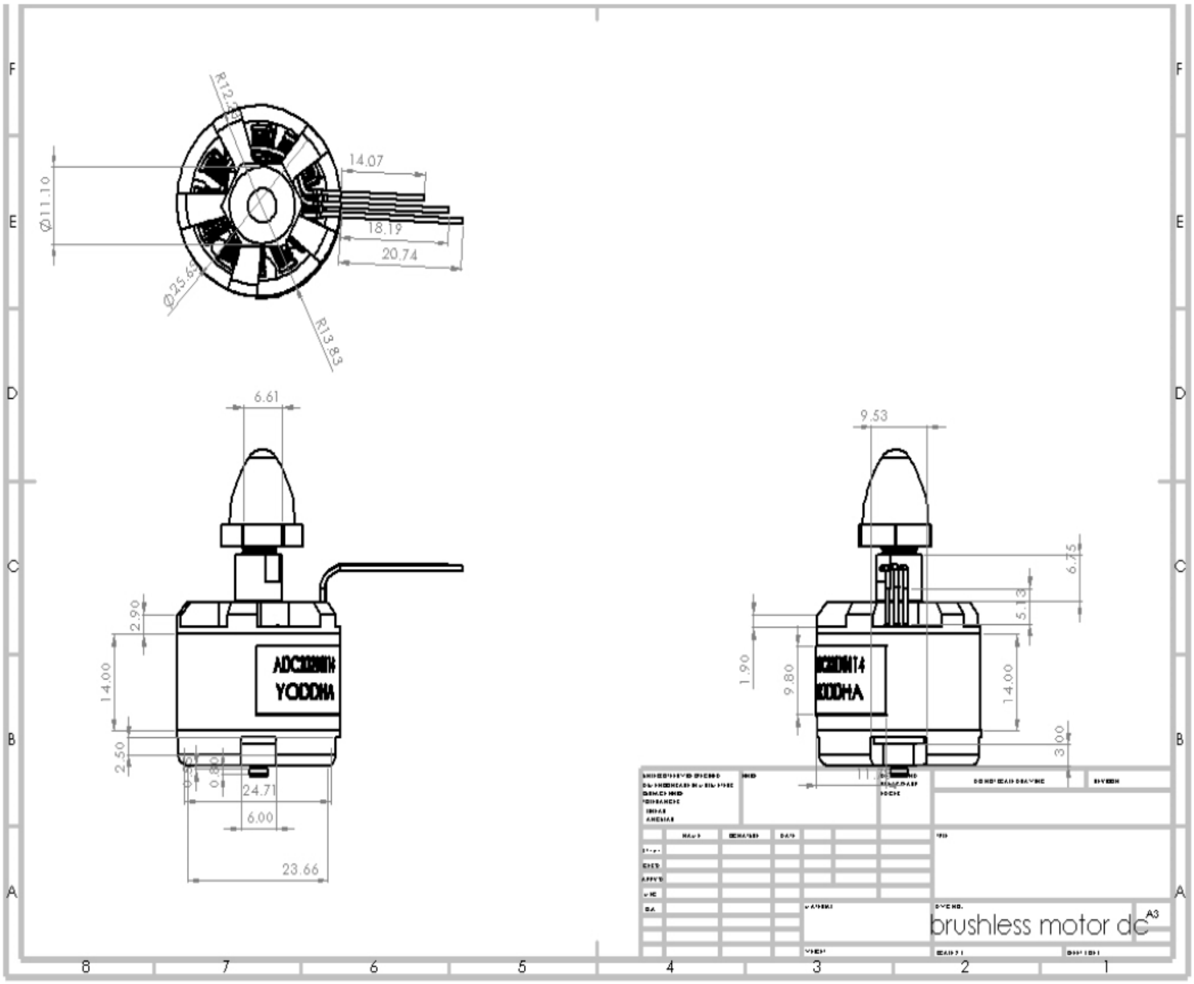
1. LITERATURE REVIEW:

The main objective of this fabrication report is to build and fabricate a fully-functional Brushless direct current motor (BLDC). This report required a lot of research as to the extent of what was possible. Using a general radial flux motor concept, the design was refined. The BLDC motors are selected due to simplicity in design, high RPM capabilities, and high durability. Internal BLDC electric motor is an important type of these motors built with permanent magnets inserted in the centre of the steel rotor and not needed to be glued. The leakage path of internal magnetic motors usually comprises a saturated magnetic bridge and web, which generates the coefficient of flux leakage variable. In this report, we selected lowest torque angle at the rated power and speed in the design, which would effectively increase the overload handling capacity and provide more torque/time.

Like all other motors, BLDC motors have a rotor (made of permanent magnets) and stator and is made of laminated steel stacked up to carry torque. The windings on a stator can be arranged in two patterns, i.e., a star mode (Y) [High Torque at Lower RPM] or delta mode (Δ) [Low Torque at Lower RPM]. The Steel laminations can be slotted or slot-less. Since the air gap, out of necessity to fit the windings in a slot-less space, is higher, more-magnet material is needed for the magnetic flux to traverse more significant air gap, and also higher cost bears a disadvantage. The manufacturing challenges to make a rigid winding structure with teeth and no lamination slots to contain the magnet wires are non-trivial, also requiring higher labour capacity.

For a micro class aircraft, the number of poles of a rotor will be 4 and 12 integral slots. Increasing the number of poles gives better performance meanwhile reducing the maximum possible speed. Another rotor parameter that imparts maximum torque is the material (here- Neodymium magnet) used in the construction of a permanent magnet.

2. CAD DESIGN OF MOTOR:



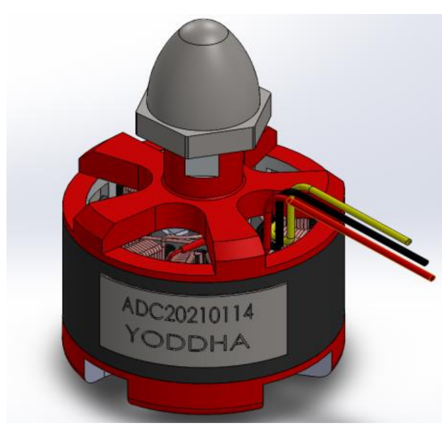


Fig 1: CAD Design of BLDC Motor

3. THEORETICAL ESTIMATION OF PERFORMANCE OF THE COMPONENTS OF MOTOR:

Applying the finite element method in the analysis of the electrical machines enables the designer to determine the behaviour of the component. It is possible to determine the electromagnetic parameters with a very high accuracy by applying a FEM method. The region to be solved is divided into small number of finite regions. The desired values are assumed to be constant over these regions. The corner points values of all the elements present in the region are chained together. A group of linear equation as much as the number of nodes is obtained as a result.

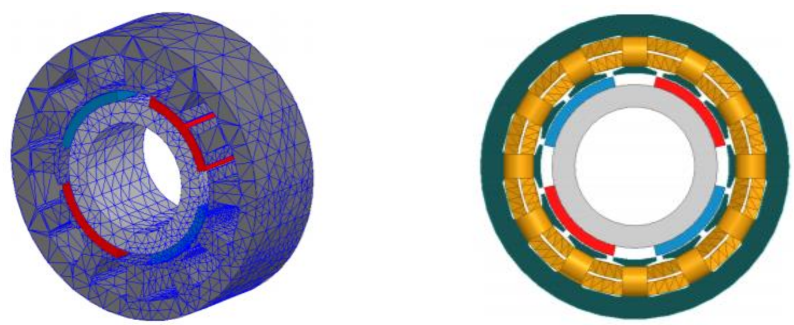


Fig.2 Design parameters

STATOR	Outer diameter(mm)	22
	Inner diameter(mm)	8.50
	Length(mm)	13
	Core material	M270-35A
ROTOR	outer diameter(mm)	27.66
	inner diameter(mm)	23.66
	length(mm)	23
	core material	ST37
MAGNET	Type	NH40UH
	Thickness(mm)	1.60
	Width(mm)	4
SLOT	Slot clearance(mm)	2

Our design aim to indulge with the maximum slot fill factor and similar efficiency values to obtain balanced copper loss which is a crucial. factor to calculate efficiency.

Full load	Output power(W) Efficiency(%) Rated torque(Nm)	100 80.2 0.312
No load	Cogging torque(Nm) Stator teeth flux density(T) Rotor yoke flux density(T)	0.204 1.79 1.71
	Stator slot fill factor(%)	51.3

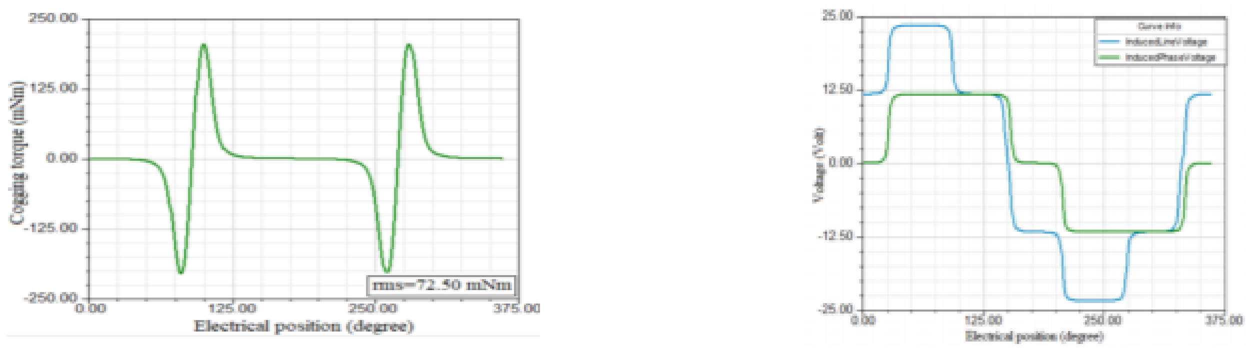


Fig.3 a) Cogging torque value & b) Line and phase voltage waveforms

The magnetic field calculations are expressed by Maxwell's equation and flux distribution is obtained by 3 D analysis.

$$\nabla \times \vec{H} = \vec{J}$$
$$\nabla \times \vec{E} = -\frac{\partial B}{\partial t}$$
$$\vec{B} = \nabla \times \vec{A}$$
$$\nabla \times \left(v \nabla \times \vec{A}\right) = \vec{J}$$
$$\frac{\partial}{\partial x}\left(v\frac{\partial A}{\partial x}\right) + \frac{\partial}{\partial y}\left(v\frac{\partial A}{\partial y}\right) + \frac{\partial}{\partial z}\left(v\frac{\partial A}{\partial z}\right) = -\vec{J}$$
$$B = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

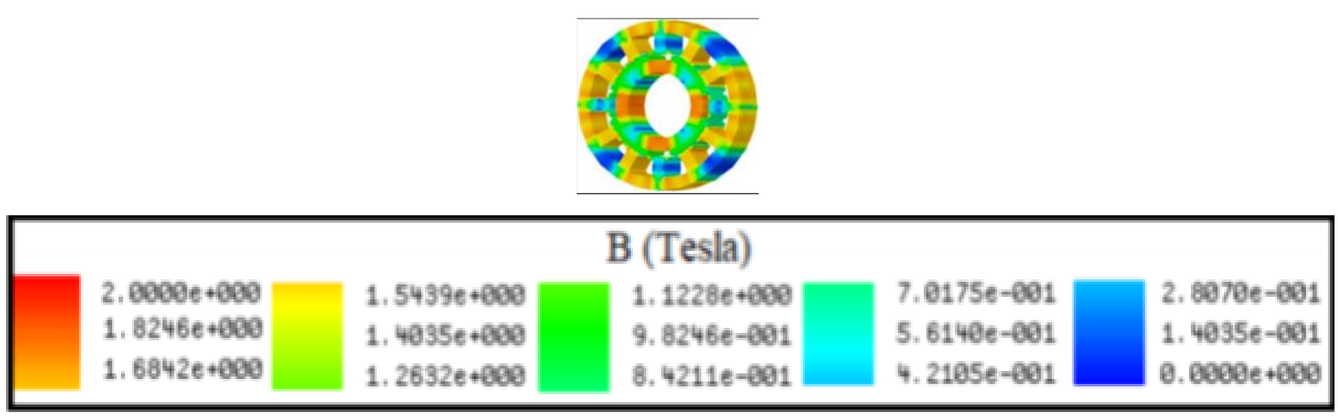


Fig.4 3D Analysis

MOTOR CALCULATION - EXAMPLE (1000 Kv)

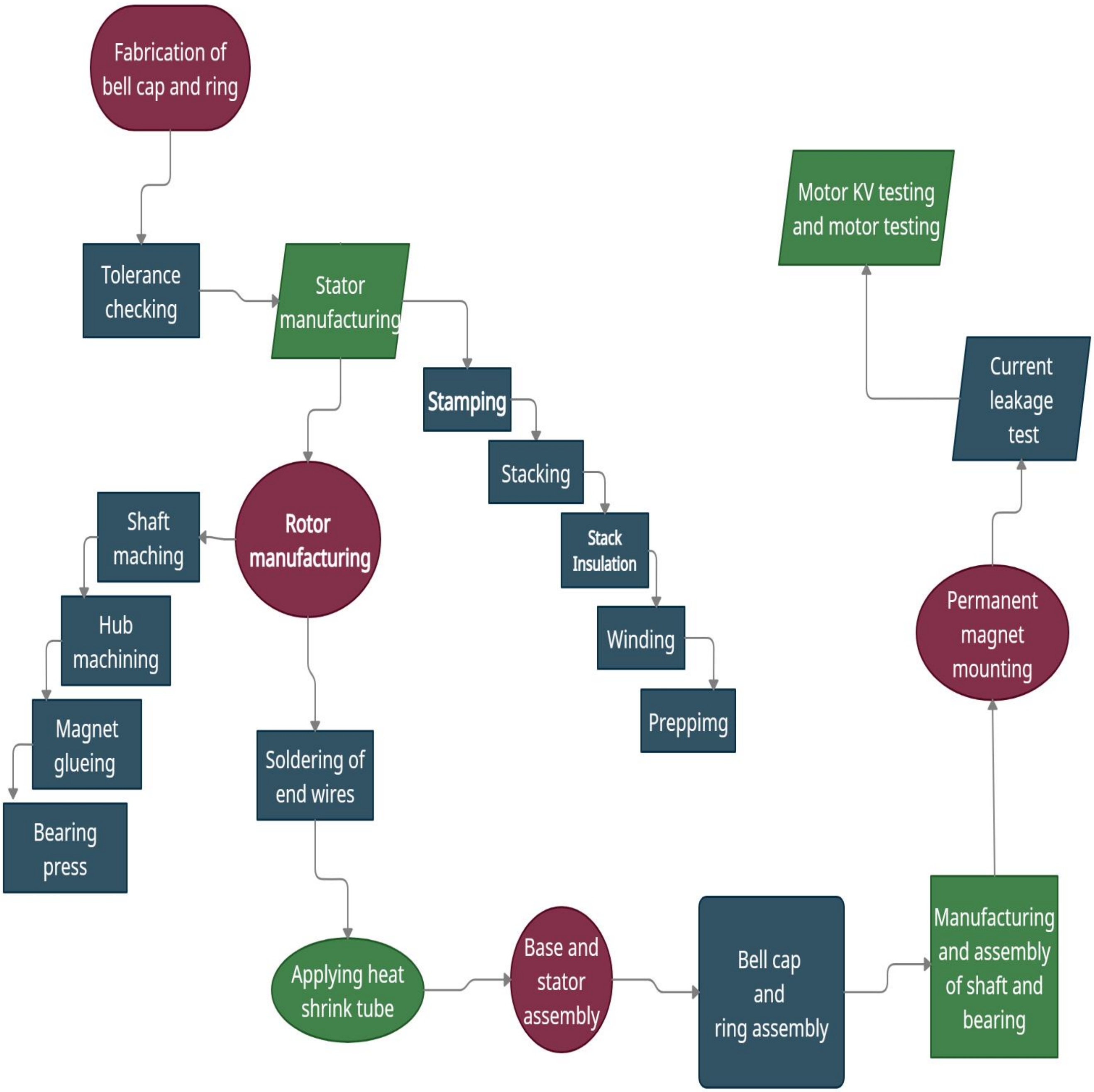
MOTOR SPECIFICATIONS	**MOTOR DATA**
1000kv; I_o=0.5 @ 10V; R_m= 0.090Ω Calculating motor parameters at I= 9A, 5V	Kv=RPM per volt ; R_m= motor resistance in Ω I_o= No load current Kq=(30/Pi*kV); kq= Torque constant Kq=**0.00955**
RPM and TORQUE AT CUREENT I	MOTOR EFFICIENCY
RPM= Kv(I – I_o)=1000(9-0.5)=8500 Q= Kq(I – I_o) = 0.00955(9-0.5**)= 0.0812 N-M** ; where Q is torque	η= Mechanical power out/electrical work in η= (V- I R_m)(I - I_o)/(V I) ; η= (5-9*0.090)(9-0.5)/(5*9) **= 0.80** Efficiency**= 80%**
CURRENT AT MAX EFFICIENCY	TORQUE AT MAX EFFICIENCY
I_{max}= √(V I_o/R_m)=√(5*0.5/0.090)=**5.27A**	Q_{max}= Kq (I_{max} – I_o) =0.00955(5.27-0.5)=**0.0455N-M**
RPM AT MAX EFFICIENCY	CURRENT AT MAX POWER OUTPUT
RPM_{max}= Kv(V – I_{max} R_m) =1000(5-5.27*0.090) =**4526**	Ip= (V + R_m I_o)/ (2 R_m) = (5+0.0908*0.5)/(2*0.090)≈**28 A**
TORQUE AT MAX POWER OUTPUT	RPM AT MAX POWER OUTPUT
Qp= Kq (I_p - I_o)=0.00955(28-0.5)=**0.263N-M**	RPM_p= Kv(V – I_p R_m) =1000(5-28*0.090) = **2480**
MOTOR MAXIMUM EFFICIENCY	TORQUE AND RPM AT MAX EFFICIENCY
$η_{max}$= [1- √($I_o R_m$ / V)²] =[1-√(0.5*0.090/50)²]=**0.90** η = **90%**	Q_{max}= Kq (I_{max} – I_o)=0.00955(5.27-5)=**0.0455N-M** RPM_{max}= Kv(V – I_{max} R_m) =1000(5-5.27*0.090) =**4595**

Table 1: Analytical method for calculation Example (1000 Kv)

Where,

Kv	= RPM per volt.	**R_m**	= motor resistance in Ohms.
I_o	= No load current.	**Kq**	= Torque constant
η	= motor efficiency	**Q**	= Torque
V and I	= working voltage and current.		

4. FLOW CHART CONTAINING THE REQUIRED STEPS/PROCEDURE TO FABRICATE THE MOTOR:



5. SPECIFICATION AND COST OF HARDWARE AND SOFTWARE MACHINE REQUIRED TO FABRICATE THE MOTOR:

COMPONENT	QTY	SPECIFICATIONS	COST (Rs)
CNC Cutting Machine	1	Material- Stainless Steel, Max Cutting Thickness – 10mm, Cutting Method- Plasma, CNC, Max Cutting Thickness-0-500mm	14,00,000 /-
CNC Winding Machine	1	Material- Mild Steel, Max Speed- 0-500 rpm, Wire-diameter-0-0.1 mm, Winding Motor Power- ½ HP	45,000/-
Micro-meter	1	Material-Stainless Steel, Volume-0.4 litres, Dimensions-19X10X5 cm, Weight- 300g	3062/-
Stamping Press	1	Material-Cast Iron, Size- 0.5 Ton Capacity, Weight- 20.8 Pounds, Brand- HHIP, Dimensions- 12X8X8 inches	5606/-
Soldering Kit	1	Includes High-Quality 25W Electric Soldering Iron, Soldering Paste, wire, stamp,	297/-
Hot Air Gun	1	Dimensions- 250X200 mm, Power- 1800 watts, Temperature-400-500 degree centigrade, Voltage- 230V	795/-
Epoxy Adhesive	1	Name- Fevitite Super Strong, High Cohesive Strength, Negligible Shrinkage, Good dimensional Stability	314/-
Pneumatic Press	1	Brand- Delta, Max Stroke- 70mm, Input Supply- 6-8 Bar of Compressed Air, Adjustable Timer Controlled	19,500/-
Neodymium Magnets	10	Material- Sintered Magnetic Material, Plating- Epoxy Black	15X10/-
Multi-meter	1	3digit ,1999 counts,600 AC/DC voltage,2000K ohm, Accuracy= +-0.8% readings (dc volt),+-1.25 readings (ac volt)	619/-
Motor bearing	2	material -Stainless steel, Inside diameter =3.17mm, outside diameter=6.35	125/-
Hall effect sensor	3	Output current=25 ma, power supply voltage=4.5 to 24v	399/-
Heat shrink tube	1	Diameter=1mm, Shrink ratio=2:1, Length=5m	49/-
Miscellaneous			20/-

Table 02: Cost of hardwares

SOFTWARES:

- SOLIDWORKS - Used to develop 3D designs of components of BLDC motor.
- ANSYS - Used for finite element analysis.
- SIMULINK - Used for torque, efficiency and power estimation.

6. DETAILED DESCRIPTION AND STEPS INVOLVED IN FABRICATION OF MOTOR:

The following points include the detailed description of the fabrication of BLDC motor for RC plane:

- **Fabrication of bell cap and base**: Bell cap is the top portion of the motor, i.e. propeller gets attached here, and the rings are the magnets that get attached to it. Bell cap is made because it is lightweight and has high strength. The stator is also made from aluminium. For manufacturing the component, we will use a machine.

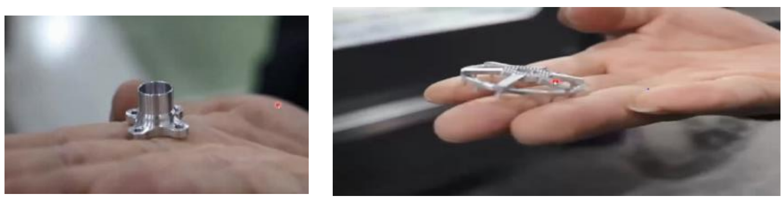


Fig 5: fabrication of bell cap and base

- **Tolerance checking:** Tolerance for this particular component is 0.001mm if the the component is not under tolerance, we will recycle the component and manufacture it again. Tolerance checking is done two times, firstly during manufacturing and secondly during an assembly where motor bell caps will get measured and visually inspected. We will attach a shaft to it to see if its measurement, as well as mass distribution along with the rotor, is correct or not. If the mass is not proper, it will create vibrations, means component should be recycled again. Usually, a micrometre is used to measure the depth of the shafts in motors with hollow shafts.

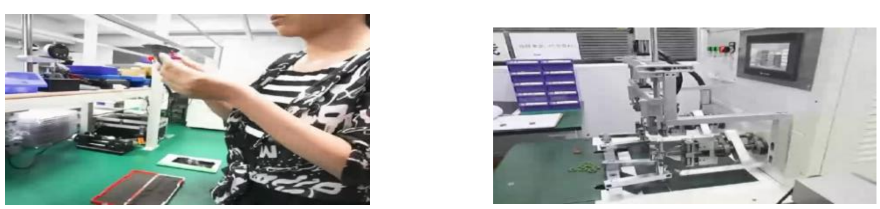


Fig 6: Tolerance checking, stator manufacturing

- **Stator manufacturing**: The first step is to stamp the steel lamination out in the proper geometry with a suitable stamping die and stamping press. Low lost electrical steels such as M19 with surface coating for rust protection are being used because a poorly manufactured lam can cause heating, loss of efficiency, and final assembly problems. Once the lamination is stamped, they are stacked using gluing and then get insulated with an electrostatic coating to insulate the copper wire from the sharp edges of the laminated steel stack.
- **Winding process**: This is the most crucial part during the fabrication of the motor. As we are manufacturing motor for RC plane, we will do Star or Y type winding because we require high torque at low RPM. We will place the stator part in the machine for winding; based on our requirements for torque and rpm, we have chosen the 0.3mm diameter of the wire. Here in the machine, automatic winding of stator will take place; the type of winding is programmed in the machine itself. After winding, the wire will be cut manually.

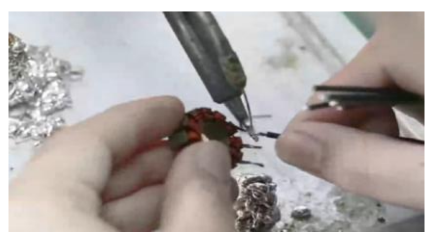


Fig.7: winding process, soldering of wires

- **Soldering end wires:** The winding wire that was cut manually will get soldered manually. This will include the soldering of winding wire with high gauge wire.
- **Applying heat shrink tube**: After soldering, we will apply a heat shrink tube so that each of the coils will get separated. For this, we will use a hot air gun.

Fig.8: heat shrink tube, stator and base assembly

- **Stator and base assembly:** we will apply glue at the base and will press it with the stator manually until it gets attached to it.
- **Bell cap and ring assembly**: we will use the pneumatic press because we need uniform pressure to attach them. After attaching the magnets (neo rings), we will glue them properly.

Fig 9: bell cap and ring assembly fit, shaft and bearing

- **Shaft and bearings:** The shaft gets attached to the bell cap as the propeller mounts on it. The material used to make a shaft is stainless steel. We will select the bearings on the basis of shaft diameter, which is later inserted inside particular rotor's base. The main function of bearings is to avoid friction between the rotor and the base of the stator.
- **Permanent magnet mounting:** We are using neodymium magnets that we will attach to the stator. It will attach to metal rings with a proper orientation of north and south as per the requirement of the magnetic field. The magnet gets inserted in the bell and ring housing. The metal ring and magnet will be glued together to avoid disturbances during rotation. After the magnets are installed, the excess glue is cleaned and will do the visual inspection before curing the glue in the oven for one hour.

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Fig 10: permanent magnet mounting

- **Current leakage test:** After assembling all the parts of the motor now, we will do the current leakage test. Here we will check the flow of current and whether the coils are properly installed or not. High voltage test checks stator for current leakage, stator that leaks more than 1mah of current will get scrapped.
- **Motor kV testing and motor testing:** Based on the coil's resistance, we will find out the KV of the motor. KV depends on the voltage and current passing through the coil. For each coil, we will check the current it is producing with a multi-meter. After motor assembly, we will check rpm as well as the vibrations. If there are small vibrations, then we will add some small mass to counteract this vibration. If there are large vibrations, then we will send them for recycling.

Fig.11: motor testing

7. GLOSSARY:

1) **FEM -** method used for numerically solving differential equations arising in engineering and mathematical modelling.
2) **LAMINATION –** Process of manufacturing material in multiple layers to improve its strength, stability and other properties.
3) **Shaft -** A rotating machine element which usually circular in cross-section that transmits power from one part to another.
4) **Slot-less motor –** It does not have stator teeth or their corresponding slots, so there is zero cogging torque.
5) **Stator -** Its purpose is to provide a rotating magnetic field which drives the rotating armature.

8. REFERENCES:

- ELECTRONICALLY COMMUTATED MOTORS (Electric Motors),http://what-when-how.com/electric-motors/electronically-commutated-motors-electric-motors/
- Justin Dameile, Brushless DC motor design and build, June 2011.
- Performance evaluation of brushless DC permanent magnet motor using Finite Element Method, ResearchGate, May 2011.
- Prof Jiji K.S, Three phase BLDC MOTOR, Nov 9, 2014.
- Manoj Kumar Pandey, Dr Anurag Tripathi, and Dr Bharti Dwivedi, FEA of a High-Efficiency Brushless DC Motor Design.
- Andrew Gong∗, Rens MacNeill and Dries Verstraete, The University of Sydney, Sydney, NSW, 2006, Australia, Performance Testing and Modelling of a Brushless DC Motor, Electronic Speed Controller and Propeller for a Small UAV.