Summary:

A synchronous machine is an AC rotating machine whose speed, under steady state condition is proportional to the frequency of armature current. Synchronous machines are commonly used as generators, especially for large power systems, such as turbine generators and hydroelectric generators in the grid power supply. Synchronous motors require DC excitation which must be supplied from external sources. Synchronous motors are inherently not self-starting motors and needs some arrangement for its starting and synchronizing. Now we have to set a dc field on the rotor of a synchronous machine. Although stator of synchronous machine is same to that of an induction motor which is available in the market, we had to modify our rotor. It was a difficult job as we did not have any equipment to cut the iron core of the rotor. Finally we took help of a workshop to cut the rotor. The rest of the works were done by solely us.

Introduction:

A synchronous machine is an AC rotating machine whose speed under steady state condition is proportional to the frequency of the current in its armature. The magnetic field, created by the armature current rotates at the same speed as that created by the field current on the rotor, which is rotating at the synchronous speed, and a steady torque results. Because the rotor speed is proportional to the frequency of excitation, synchronous motors can be used in situations where constant speed drive is required. Since the reactive power generated by a synchronous machine can be adjusted by controlling the magnitude of the rotor field current, unloaded synchronous machines are also often installed in power systems solely for power factor correction or for control of reactive kVA flow.

There are two parts of synchronous machine: **Rotor** and **Stator**.

Rotor is the moving part. It rotates because the wires and magnetic field of the motor are arranged so that a torque is developed about the rotor's axis. In some designs, the rotor can act to serve as the motor's armature, across which the input voltage is supplied.

Stator is the stationary part. Depending on the configuration of a spinning electromotive device, the stator may act as the field magnet, interacting with the armature to create motion; or it may act as the armature, receiving its influence from moving field coils on the rotor.

Structure of the Stator:

We built the structure of the stator through some steps.

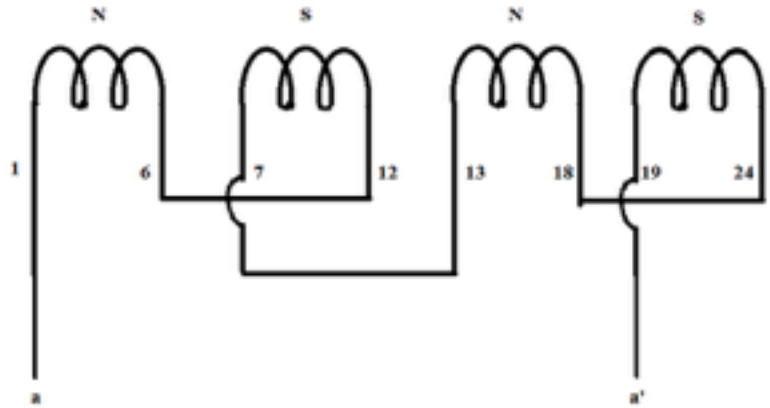
1. We bought a stator of 24 slots and we are using 28 swg wire. As we have decided to make a machine of 4 poles. We have decided to give full pitch winding. So each coil must span 6 slots as each pole spans 6 slots (24/4).

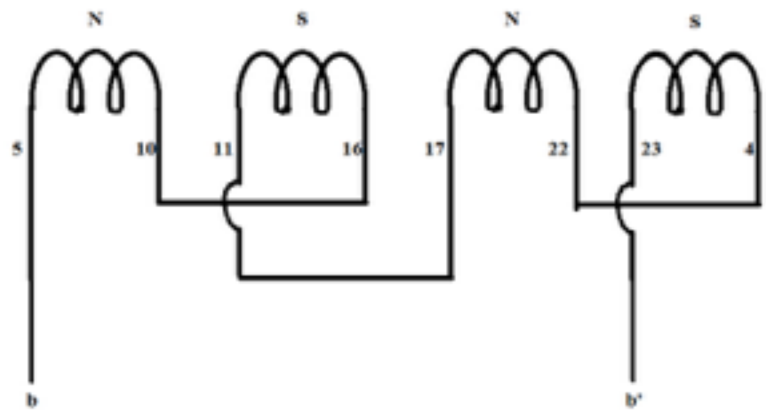
So in stator, if on one side first coil is inserted in number one slot then the other side must be inserted in number 6 slot.

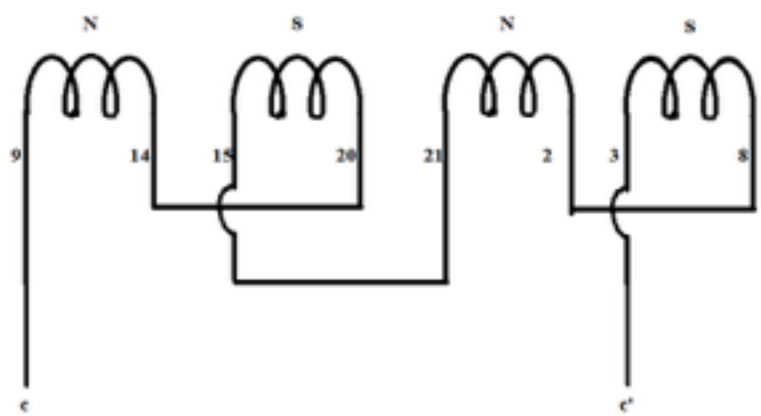
2. When the rotor fully circulates one single time electrical degree passed 720 degree. So each slot consists of electrical (720/24) 30 degree. So, if we want to make three phase, there must be 120/30=4 slots gap between each phase.

3. We are giving here Y connected connection, so one side is shorted of each phase.

Wire Diagram







Stator Calculation:

Here we had no scope of designing the stator, as it was bought readymade, so the pitch factor (K_p) and Distribution Factor (K_d) are both 1.

Let, we use 28 swg in stator.

Let us consider, our motor has an efficiency of 60%. As we are making a machine of 0.5 HP, so our input power is 621.67 W. Considering power factor is unity,

$$Pin = \surd 3\ V_L\ I_L$$

Or, $746/2 = \surd 3\ V_L\ I_L$

Or, $I_L = 0.54$ Amperes

So we are using a wire of 28 swg as it has 1.3 Amperes current rating.

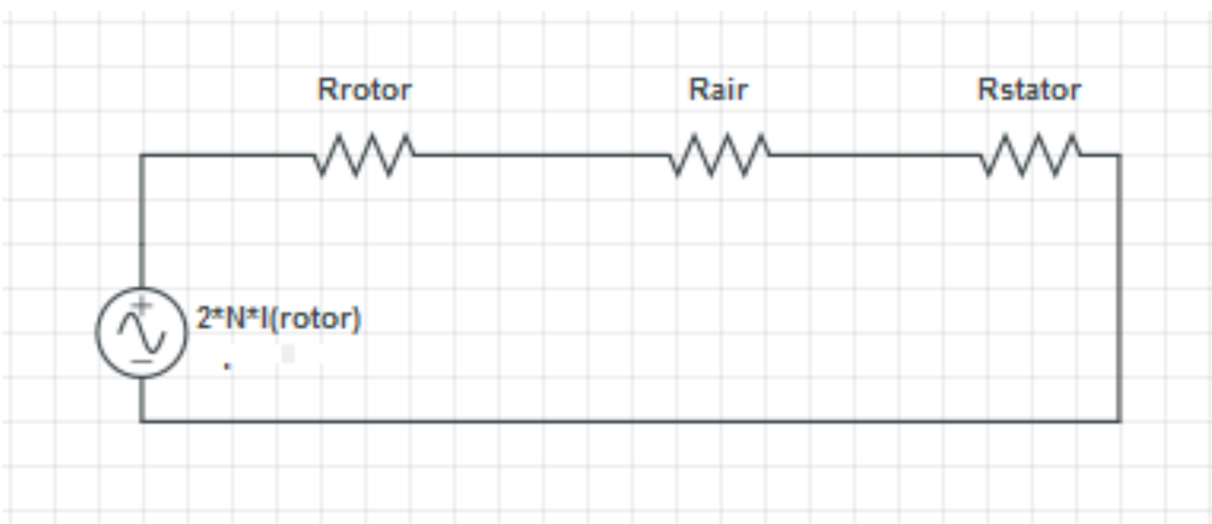


Fig: magnetic circuit diagram

R =

Here, l_{air}=2x10^{-2} m

Perimeter of rotor= 23.5x10^{-2} m^2

Height of the core= $8x10^{-2}$

$\mu_0=4\pi x10^{-7}\ Hm^{-1}$

$\mu_r=3.6x10^3\ Hm^{-1}$

$l_{rotor}= 1.5x10^3$ m

perimeter of stator= 31.41×10^{-2} m

$A_{air}= 8x10^{-2}x23.5x10^{-2}\ m^2$

[It was approximated to be equal to rotor's surface area]

R_{air} =

$=846.568x10^3\ H^{-1}$

R_{stator}=

$=13.19\ H^{-1}$

R_{rotor}=

$=440\ H^{-1}$

$\phi_{induced}$=

=

$= 1.785x10^{-3}$ Wb

E= 4.44ΦNf

N_{total} =

=

= 605 turns

N_{per_coil} = 605/4

=151 turns

We took 200 turns-per-coil for safety.

Rotor Structure:

To construct the rotor of our machine, we had to cut the rotor of a squirrel cage induction motor so that we could place dc field in that. Our rotor is .12 m long and its radius is 4 cm. So, the perimeter becomes 2*3.1416*4= 25.138 cm, so our rotor is tightly fitted inside the stator.

There are two coils 180 degree apart in the rotor. The coils are connected in series so that the poles created for dc current do not conflict with the stator rotating magnetic field.

For continuous dc excitation, brushes and slip rings are provided in the rotor shaft.

Rotor Calculation:

Let, we use 30 swg in rotor, which has 0.455 Ω/m per unit length resistance for safety measurement.

Rotor coil length= 0.12m

Rotor coil width= 0.04m

So, full length= 0.32m

We get 2800 turns

R=2800x0.32x0.455

= 407.68 Ω

I=V/R

=0.54A

As, 30swg wire's rated current is 1.0 A, our pre-measurement ensures safety.

We took help in our assumptions in our calculation from the following table:

AWG	SWG	Diameter	CSA	Fusing Current	Fuse Rating	Wire Rating
		Mm	sq mm	Amps	Amps	Amps
32		0.202	0.032	7	4	0.4
	35	0.214	0.036	8	4	0.5
31	34	0.226	0.04	9	5	0.5
	33	0.250	0.049	10	5	0.6
30		0.255	0.051	10	6	0.7
	32	0.269	0.057	11	6	0.8
29	31	0.288	0.065	12	7	0.9
	30	0.315	0.078	14	7	1.0
28		0.321	0.081	15	8	1.3
27		0.362	0.103	17	10	1.4
	28	0.397	0.124	20	10	1.6
26		0.404	0.128	21	10	1.7
	27	0.410	0.132	21	12	1.7
25	26	0.454	0.162	24	14	2.1
	25	0.496	0.193	28	15	2.5
24		0.517	0.21	30	17	2.8
	24	0.559	0.245	33	17	3.2
23		0.574	0.259	35	19	3.4
	23	0.613	0.295	38	21	3.9
22		0.642	0.324	41	25	4.3
	22	0.723	0.41	49	25	5.4
21		0.724	0.412	49	29	5.4
	21	0.807	0.511	58	31	6.7
20		0.841	0.556	62	34	7.3
19		0.900	0.636	68	35	8.4
	20	0.917	0.66	70	41	8.7
	19	1.017	0.813	82	42	10
18		1.026	0.826	83	49	11

17		1.151	1.04	99	54	14
	18	1.221	1.17	108	60	15
16		1.306	1.34	119	69	18
	17	1.441	1.63	138	71	21
15		1.463	1.68	141	83	22
14	16	1.627	2.08	166	99	28
13		1.830	2.63	198	99	35
	15	1.833	2.64	199	116	35
	14	2.034	3.25	232	139	43
11		2.293	4.13	278	147	54
	13	2.386	4.47	295	167	59
10		2.588	5.26	333	170	69
	12	2.620	5.39	339	197	71
9	11	2.899	6.6	395	237	87
8		3.270	8.4	473	270	110
	10	3.568	10	539	282	130

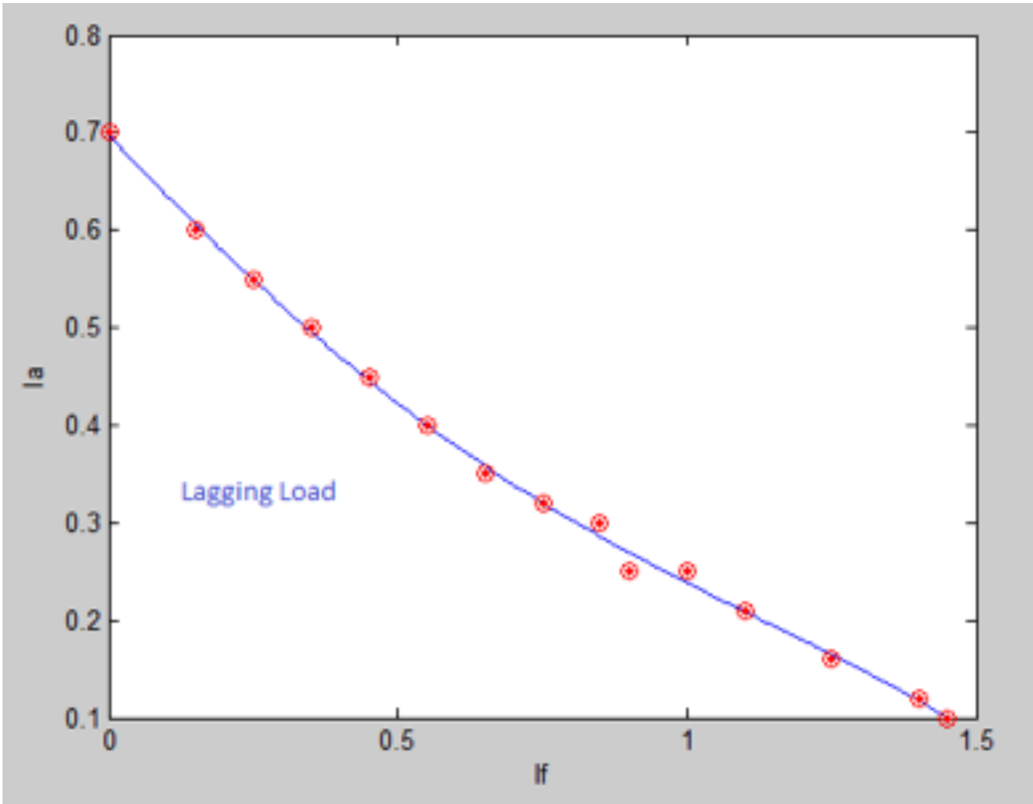
Source:www.gxk.org.uk/info/wire.htm

Experimental Calculation:

I_F (A)	I_A (A)
0	0.7
0.15	0.6
0.25	0.55
0.35	0.5
0.45	0.45

0.55	0.4
0.65	0.35
0.75	0.32
0.85	0.3
0.90	0.25
1.00	0.25
1.10	0.21
1.25	0.16
1.40	.12
1.45	.1

Graph:



No load Test:

Experimental Data:

V= 400V (Rated Voltage)

$I_{L(No\ load)}$= 0.7A

$P_{(No\ load)}$= 36W (Per Phase)

$P_{(No\ load)}$= (36x3) W (3 phase)

= 108W

So, core loss= 108W

Our Calculated rated load current was = 0.54 A (mentioned in our stator coil calculation)

$I_{L(No\ load)}$= 0.7A

So, our blocked rotor test was done at, I= 0.54+0.7 A =1.24 A

Blocked Rotor Test:

I= 1.24 A

P = 140W (Per Phase)

P= 140W x 3 (3 phases)

$P_{Cu,loss}$= [140x3 – 108 x (300/390)^2] = 356.1 W

P_{output}= 0.5 x H.P.= 373 W

Efficiency, $\eta = \{P_{output}/(P_{output}+P_{cu,loss})\} \times 100$ %

= 44.56%

Discussion:

Although we thought we could manage to build a machine of 60-70% efficiency, we find after experimental calculation that, it is just 44%. There may be many reasons behind this.

Our motor was vibrating, probably because our rotor did not fit properly into our stator.

It is also apparent that the bearing did not fit as well.

Because of our excess frictional loss, the no load current exceeded full load current. Despite that, our wire did not burn as the safety factor regarding stator wire was high.

The expected V-curve was not attained, rather only the lagging part was observed. To get the full V curve, we required much reactive power, hence implying extra field current. But the highest limit of DC supply of our lab is 220V. Also, it may be added, if we managed to use more than 220V it might have burnt the wire.

Conclusion:

Despite many challenges, we have managed to build our machine. Our concept about machine designing is very primary, so we couldn't do it properly. But this experience has enriched our ideas about various aspects of synchronous machines. Hopefully, we shall be able to build better machines in future.

Reference:

"A Course in Electrical Machine Design" by Sawhney & Chakrabarti.