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Design and analysis of frictionless brake for wind turbine

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ABSTRACT

The current induces the reverse magnetic field and results in the deceleration of motion. The eddy-current is created by the relative motion between a magnet and a metal (or alloy) conductor. The proposed mechanism implements this phenomenon in developing a braking system. The potential applications of the braking system can be decelerating system to increase the safety of wind Turbine system. To provide scientific investigation for industrial application of magnetic braking, this study presents systematic engineering design scenarios to design a braking system. The constant magnetic field is the simple stand easiest design to implement. The optimal magnetic field distribution is obtained by minimizing the deceleration effort. The constant magnetic field distribution offers a compromise between performance and magnetic field requirements. The advantages of Frictionless Brake for safety against the failure under maximum wind intensity; and simple design requirement and manufacturing processes. In the study, an experimental braking system using constant magnetic field is built to demonstrate the design procedure.

Keywords— **Braking force, Deceleration,Eddy current generation, Piece of magnet, Wind Turbine.**

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I. INTRODUCTION

An eddy current is a swirling current set up in a conductor in response to a changing magnetic field. By Lenz's law, the current swirls in such a way as to create a magnetic field opposing the change; to do this in a conductor, electrons swirl in a plane perpendicular to the magnetic field. Because of the tendency of eddy currents to oppose, eddy currents cause energy to be lost. More accurately, eddy currents transform more useful forms of energy, such as kinetic energy, into heat, which is generally much less useful. In many applications the loss of useful energy is not particularly desirable, but there are some practical applications. One is in the brakes of some trains. During braking, the metal wheels are exposed to a magnetic field from an electromagnet, generating eddy currents in the wheels. The magnetic interaction between the applied field and the eddy currents acts to slow the wheels down. The faster the wheels are spinning, the stronger the effect, meaning that as the train slows the braking force is reduced, producing a smooth stopping motion. Without using friction, an eddy-current braking system transforms the kinetic energy of the moving body into heat energy that is dissipated through the eddy current in the conductor. However relative velocities between the magnet and the conductor are required to activate an eddy-current braking system. Because of the simplicity of this mechanism, it can be used as a decelerator or auxiliary braking system to ensure the safety of system. Studies on the actuation of electro-mechanical machines using an eddy current can be traced back to the early 20thcentury. The mathematical description of the eddy current induced in a conductor under varying magnetic fields is rather complicated.

Therefore, in developing eddy current braking systems, designers usually make certain assumptions to allow a simple mathematical representation of the magnetic field.

This makes it possible to derive the analytic solution of the induced eddy current distribution caused by the interaction between the moving conductor and the magnetic field. In this study, four systematic engineering design scenarios to design a braking system are presented as constant magnetic field, an optimal magnetic field distribution, piecewise constant magnetic fields and a section-wise guide rail with a constant magnetic field. The constant magnetic field is the simplest and easiest design .The rotating plate carries the magnets on periphery connected to wind turbine shaft and stationary plate connected to generator. Magnets passing through the conductor induce an eddy current in the copper or Al, inducing drags that decreases motion. To achieve better performance, the smaller gaps between the copper and magnets are required to reduce the deformation of the copper strips, they are divided into sections. Based on the magnetic braking system above, we used the approximate mathematic model of the magnetic field to derive the braking force caused by the eddy current.

II. ANALYTICAL DESIGN

Given Data-:
Wind speed (Vw) = 13m/s
Coefficient of pressure (Cp) = 0.35
Air density (Ad) = 1.22 kg/m3
Height (H) = 1m
Diameter (D) = 1m
Velocity coefficient (Tsr) = 0.7
Swept area (S) = D*H
S=1*1
S=1m2

A. Design of shaft

Power = (½)* Ad * S * V3 * Cp
P = 0.5 * 1.22 * 1 * (13)3 * 0.35
P = 496.05 W
Tsr = Vtip/Vair
0.7 = Vtip/13
Vtip = 9.1m/s
V = (3.14 * D * N)/(60)
N= (60 * 9.1)/(3.14 *1)
N= 174 r.p.m
P = (2 * 3.14 * N *T)/60
496.05 = (2 * 3.14 * 174 * T)/60
T = 27223.72 N – mm
τs = (16 * T)/(3.14 * d3)

TABLE I
TABLE 3.1 PROPERTIES OF MATERIAL FOR SHAFT

Material designation	Tensile strength(N/mm2)	Yeild strength (N/mm2)
C45	600	320

Syt = 320 N/mm2
f.o.s = 2
σb = 320/2
σb = 160 N/mm2
τs= 0.5 * 160
τs = 80 N/mm2
Now from above formula,
0.5syt/f.o.s = 16t/(3.14 * d3)
(0.5*160)/2 = (16* 27223.73)/ (3.14 * d3)
d = 19.76 ~ = 21mm
τsind = (16 * 27223.73)/(3.14 * (21)3)
τsind = 14.97 N/mm2
τsind<τs
So our design is safe
Selection of bearing:-
6204
Where,
6 = deep groove ball bearing
2 = light series
04 = it indicates the bore.

B. Arm design

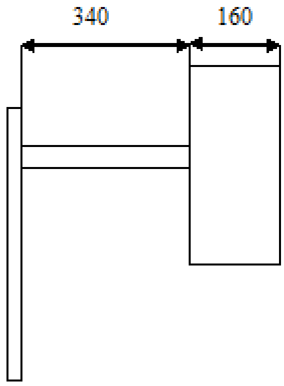

Fig.1 Arm of the turbine

TABLE II
PROPERTIES OF MATERIAL FOR ARM

Material designation	Tensile strength(N/mm2)	Yeild strength (N/mm2)
C45	600	320

Let the total length is given by
L = 340 + (160/2)
L = 420
Moment M is given by
M = F * L
Now to calculate the drag force on blade we have the following formula,
Fd = Cp * 2 * A * ((Uw – Ub)/2);
Where,
Uw = speed of wind
Ub = speed of blade
Fd = 0.35 * 2 * 1 * 1 * ((249 – 174)/2);
Fd = 26.25 N
M = 26.25 * 420
M = 11025 N- mm
Let to calculate the section modulus we have

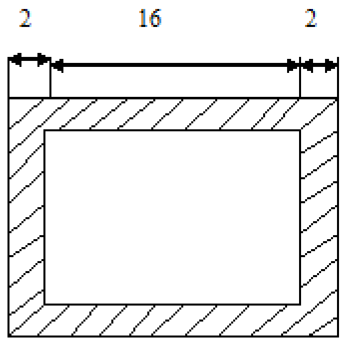

Fig.2 section of arm

σbind = M / Z
Z = (B3-b3) / 6

Z = 650 mm2
σbind = (11025 / 650)
σbind=16.96 < 160
So our design is safe

C. Frame design

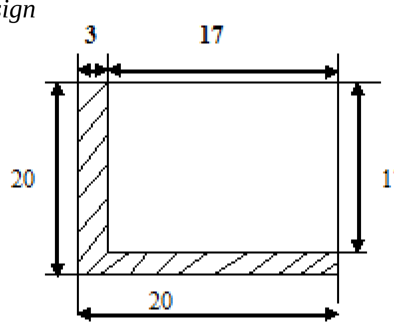

Fig.3 section of frame

M = (WL / 4) = (250 * 900) / 4 =56250 N-mm
M = 56250 N-mm
M = 56250 / 4 =14062.5 N-mm
Y = 4.7162 mm
I = ((bd3/12) + A1(Y- y1)) + ((bd3/12) + A2 (Y – y2))
I = 2624.056 mm4
Z = 556.39 mm3
σbind = 14062.5 / 556.3
σbind = 25.27 < 160 N / mm2
So our design is safe.

D.Weld joint

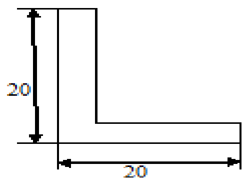

Fig.4 section of frame

S = 3.15 mm
L = 20 + 20
L = 40 mm
σsall = 21 N / mm2
f = 250 N
A = 0.707 * 3.15 * 40
A = 89 mm2
σsind = f / A = 250 / 89
σsind = 2.889 N / mm2 < 21 N / mm2
Hence welded joint design is safe.

E. Blade design

We know that the drag force on blade is given by,
Fw = (2 * Cd * A * ((Uw- Ub)/2))
Fw = (2 * 0.35 * 1 * ((249-174) / 2)
Fw = 26.25 N
Now we know that for PVC(poly vinyl chloride)
Sut=15.5 Mpa (for flexible material from design data book)
Syt = (15.5)/2
Syt =7.75Mpa
F. O. S = 1.25
σall = syt/ f.o.s
σall = 7.75/1.25
σall = 6.2N/mm2
σind = M/ Z
M = F * L
M = 26.5 * 240
M = 6300 N – mm
2Z = (π(D4 – d4) /64) / (D/2)
2Z = (π(1604 -1584) / 64) / (160/2)
Z = 9866.166 mm3
Now,
σind = 6300/9866.166
σind = 0.6385 N/mm2
hence our design is safe.

F. Magnet design

Let to calculate the braking force when wind speed is 13 m/s

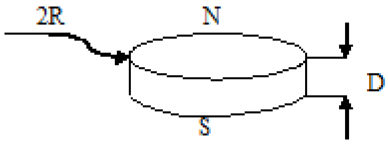

Fig.4 Nomenclature of Magnet

Br = remaining magnetization after the magnetic field removed which is use to make the magnet
Z =(δd)Distance of a plate from pole face
D = Thickness of magnet
R = Radius of magnet
Let to calculate the braking force we have the following formula,
Fb = α (σ □ B02 L W) V
Fb = Braking force
□ = thickness of conductor
B0 = Flux density in magnetic pole projection area on conducting plate
L & W = length and width of pole projection area
α = 0.2609 for permanent magnet of Neodymium iron boron (NdfeB)
σ = Conductivity of aluminum plate
Br = 1.4 for NdfeB
σ = 3.5 * 107
B0 = (Br/2)*((□+Z) / (√R2 + (□+Z)2) – (Z) / (√R2 + Z2))
B0 = (1.4/2)*((0.002+0.001) / (√0.012 + (0.002+0.001)2) – (0.001) / (√0.0012 + 0.012))
B0 = 0.7 * (0.2873 – 0.09950)
B0 = 0.13146 T
Fb = (0.2609) * (3.5*107 * 0.001 * 0.131462 * 0.02 * 0.001) * 9.1
Fb = 0.02872 N
Fbtotal = 12 * 0.02872............................. (Total no. Of pole = 12)
Fbtotal = 0.3446 N

III.EXPERIMENTAL READINGS

The Frictionless Braking system is being depends upon the intensity of wind which will provide the information about speed at which the braking action is to start for actuation at optimum speed. The variable consider for Experiment that provide idea about the required actuation at optimum speed are Kinetic Energy of wind turbine shaft (K.E), Distance between the Rotating plate & Stationary plate (δd), Time required for Braking Action (T), Angular speed of wind Turbine shaft, Braking force (F) and this parameter can be check at different Linear speed of wind Turbine shaft (V). The gap is being maintained in mm. Now the Kinetic Energy of running plate or wind Turbine shaft is being measured by Anemometer and Angular speed of wind turbine shaft is measured by Tachometer. The different graph are plotted that showing the variation of one parameter with different, that

give the actual task of braking system.

TABLE III
EXPERIMENTAL READING

Sr.No.	Gap between two plates (mm)	Speed (rpm)	Velocity (m/s)
01	2	643	13
02	3	750	13
03	8	929	13
04	16	1014	13

So from above reading we can conclude that with increasing gap between two plates R.P.M of the turbine also increases and vice versa.

IV. SOFTWARE ANALYSIS

For the analysis we are use no. of software such as a ansys, hyper mesh, mouldex Mould flow etc. but out of that the ansys is more beneficial to use because it gives good result as compare to other also it is use versatile in industry and available easily.

An analytical solution is a mathematical expression that gives the values of the desired unknown quantity at any location in the body. But analytical solution solve simple engineering problem only. It is extremely difficult, and many a times impossible, to obtain the exact analytical mathematical solutions for many complex engineering problems. In such cases, the technique known as Finite Element Method (FEM) is used.

In Finite Element method, the body is divided into finite number of smaller units known as elements. This process of dividing the body into finite number of elements is known as discretization.

The assemblage of elements then represents the original body. These elements are considered interconnected at joints which are known as nodes or nodal points. Instead of solving the problem for the entire body in one operation, the solutions are formulated for each element and combined to obtain the solution for the original body. This approach is known as going from part to whole.

Though it will be theoretically correct to satisfy the continuity requirements all along the edges of elements, this will lead to more complicated analysis. Hence, in finite element method, in order to make analysis more simpler, it is assumed that the elements are connected at the finite number of joints called nodes or nodal points. It is only at nodes the continuity equations are required to be satisfied.

In finite element method, the amount of data to be handled is dependent upon the number of elements into which the original body is divided.

For a large number of elements it is formidable task to handle the volume of data manually, and hence in such cases the use of computers is inevitable. It has been found that the accuracy of solution, in general, increases with the number of elements taken. However, more number of elements will result in increased computation.

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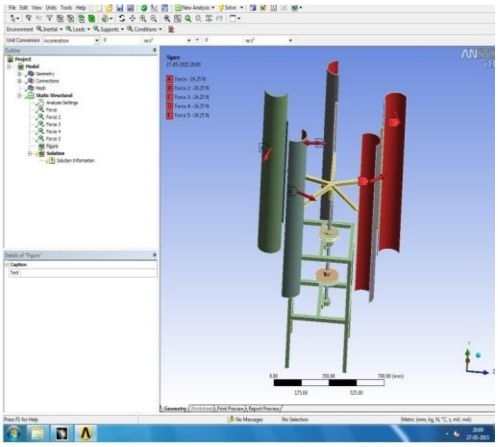

Fig.5 Force distribution

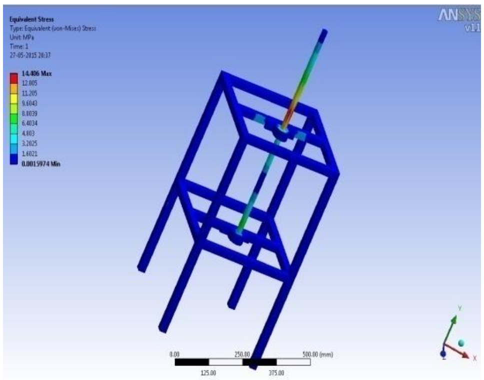

Fig.6 Analysis of shaft.

Moment on shaft = 25742 N-mm

Force = 26.25N

Induce stress = 14.406N/mm^2

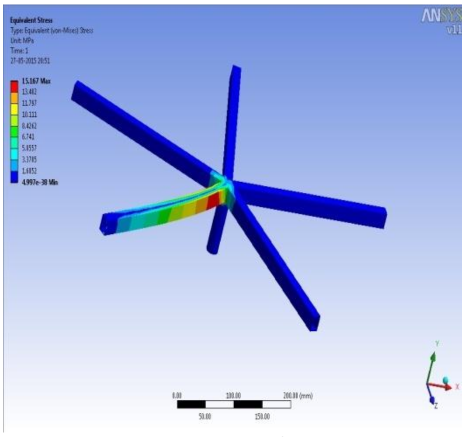

Fig.7 analysis of arm

Moment on Arm = 11025 N-mm

Wind force = 26.25 N

Stress induced = 15.142N/mm^2

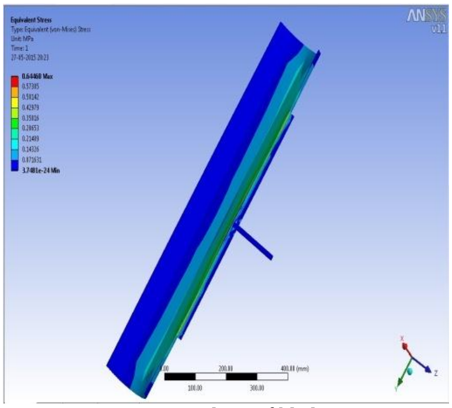

Fig.8 Analysis of blade

Force on Blade = 26.25N
Moment on blade = 6300 N- mm
Stress induced = 0.64

V. CONCLUSION

We forming the project set-up and doing the analytical design of each part of it.also from Experimental reading we can conclude that with increasing gap between two plates R.P.M of the turbine also increases and vice versa .simulation is done by the ANSYS software and getting the nearly same result as like analytical.

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