A Review on Design and Thermo Structural Analysis of Wind Turbine Disc Brake

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Abstract – **The Disc brake is one of the most important components in the brake system of wind turbine. According to the principles of braking, Disc brake receives powerful pressure and static or kinetic friction force from brake disc. Especially the sliding velocity and specific pressure increase with the speed of drive train shaft of wind turbine, which result in heavier wear and higher temperature. In order to cater to this new found problem area, the idea was to use computational methods to simulate and predict improvements needed to consider these scenarios during the design of the braking system.**

Index Terms - **Disc brake, Thermo-Elastic Instability (TEI), FEA, Rotor Brake.**

I. INTRODUCTION

A brake is a device by means of which frictional pressure is applied to a moving machine member, in order to stop the motion of the machine. Brakes govern over speed and provide emergency braking. The kinetic energy created at the rotor during braking operation is transformed into heat energy which does not dissipate immediately in to the atmosphere from brake to the disc brake. As a result of this one of the material properties such as thermal conductivity plays a crucial role in governing the frictional heat generated. Due to non-uniform contact cycles between the pad and the disc brake rotor thermal judder occurs which is primarily an effect of localized Thermo Elastic Instability (TEI) at the disc brake rotor. Localized Thermo Elastic Instability acts at the friction ring surface which generates erratic hotbands around the rubbing path, which results in the development of so called hotspots. The mechanism of the Thermo Elastic Instability phenomena taking place during the braking process has been of interest to many researchers. However, in this paper a clear view and necessity of disc brake in wind turbines is studied. FEA approach has been used for comparison of two materials (Stainless Steel and Al alloy).

K.Wang, **et al.** examined on a 5-MW vertical axis wind turbine with a Darrieus rotor mounted on a semi-submersible support structure was examined. In this paper the author has conducted study on Coupled non-linear aero-hydro-servo-elastic simulations of the floating vertical axis wind turbine for emergency shutdown cases over a range of environmental conditions based on correlated wind and wave data. When generator failure happens, a brake should be applied to stop the acceleration of the rotor to prevent the rotor from over speeding and subsequent disaster. In addition to the traditional mechanical brake, a novel hydrodynamic brake was presented to apply to the shutdown case. The effects of the hydrodynamic during the emergency shutdown events were evaluated. The use of both the hydrodynamic brake and mechanical brake was also investigated in this paper.

Frank Jepsen, et al. Discussed control of the brake torque from the mechanical disc brake in a wind turbine. The author through laboratory sized test system found that the disturbance from the brake disc/caliper to the hydraulic pressure is dependent on the shaft's speed and the position of the brake pads on the disc and an estimator has been designed, which is proven successful in estimating the amplitude of this disturbance. A disturbance rejection scheme has been applied to show that it is possible to reject the input equivalent disturbance.

Jung. S.P, et al studied the thermo elastic instability (TEI) using the finite element analysis technique. Three dimensional thermo mechanical analysis model of the disc brake system were created and TEI phenomenon was implemented by rotating the disc with a constant rotational speed. Temperature, friction contact power, nodal displacement and deformation and temperature distribution of the disc were calculated. Solutions of fully coupled thermo-mechanical system were obtained. Contact pressure distribution of the pad surface was varied according to the rotational direction of the disc.

Mazidi. H, et al. Studied the heat conduction problem of the disc brake (pad and rotor) and are modeled mathematically and solved numerically using Finite Element Method. Time dependent equations the implicit method is taken in to consideration. In this paper parameters such as the duration of braking, vehicle velocity, geometries and the dimensions of the brake components, materials of the disc brake rotor and the pad and contact pressure distribution have been taken into consideration. Results show that there is a heat partition at the contact surface of two sliding components, because of thermal resistance due to the accumulation of wear particles between contact surfaces.

G.Cueva, **et al.** Studied the wear resistance of three different types of gray cast iron (gray iron grade 250, high-carbon gray iron and titanium alloyed gray iron), used in brake disc rotors. The wear tests were carried out in a pin-on-disc wear-testing machine, the pin being manufactured from friction material usually used in light truck brake pads. In this rotating discs were subjected to cyclical pressures and forced cooled. The operating temperatures and friction forces were also monitored during each test. The wear was measured by weighing discs and pads before and after the test. The results showed that for given applied pressures the pins wear

was practically the same, independent of the iron. During gray irons tests, at given applied stresses, practically the same friction forces and
temperatures were observed, independent of the grade. Compact graphite iron on the other hand, showed greater friction forces and temperatures than those observed in gray iron.

Lee. K, et al. Thermo elastic instability in automotive disc brake systems is investigated focusing on the effect of a finite disc thickness. A finite layer model with an anti symmetric mode of deformation can estimate the onset of instability observed in actual disc brake systems. Thermo elastic instability in an automotive disc brake system was investigated experimentally under drag braking conditions. The onset of instability was clearly identifiable through the observation of non uniformities in temperature measured using embedded thermocouples. A stability boundary was established in temperature/speed space, the critical temperature being attributable to temperature dependence of the brake pad material properties. It was also found that the form of the resulting unstable perturbations or Eigen functions changes depending upon the sliding speed and temperature. A finite-element method was developed for determining the critical sliding speed for thermo elastic instability of an axis symmetric clutch or brake. Linear perturbations on the constant-speed solution were sought that vary sinusoidal in the circumferential direction and grow exponentially in time.

Daniel Das. A, et al presented a paper on structural and thermal analysis of disc brake rotor. The solid disc was compared with four different materials during short and emergency braking. The values of temperature, friction contact power, nodal displacement and deformation for different pressure conditions were taken using analysis software with four different materials cast iron, cast steel, aluminium, carbon fiber rein forced plastic. From structural and thermal analysis results the stress values are within permissible limit for aluminium and carbon fiber rein forced polymer compared to cast iron and cast steel. But the strength is more for carbon fiber rein forced polymer than that of aluminium alloy. Form analysis results it is found that carbon fiber rein forced polymer is best suited for disc brake.

M. Saran Theja, et al conducted structural analysis to validate the strength and thermal analysis to analyze thermal properties of the disc brake. Comparison was done for two different materials Stainless steel and Carbon steel for displacement, stresses, thermal gradient etc. From structural analysis, the design is safe, as the stress values are less than their respective yield values. From thermal analysis thermal gradient for carbon steel is more. From thermal analysis the author concluded that carbon steel is better material for their design and also prepared prototype for the disc brake.

Guru Murthy Nathi, et al has investigated the effect of stiffness, strength and variations in the disc brake rotor design and predicted stress and temperature distribution. An Axis-symmetric analysis is carried out using plane 55 and plane 42. Transient thermal analysis is carried out using the direct time integration technique for the time duration of 4, 5 and 6 seconds. The maximum temperature observed to be 240.161◦C. The Disc Brake design is safe based on strength and rigidity criteria. To obtain a best combination of parameters like flange width and material thermal and structural analysis for three different combinations three different analyses is carried out and comparing the results it is concluded that disc brake with 10 mm flange width, 6.5 mm wall thickness and material cast iron is possible best combination for present application.

Chengal Reddy et al showed the design, analysis and optimization of solid and vented disc brake using Pro-E, FLUENT and Ansys. The ventilated brake disc assembly is built by a 3D model in Pro-E and imported to ANSYS to evaluate the stresses and of deformations established in the disc with the pressure on the pads and in the conditions of tightening of the disc.

Eltoukhy.M, et al Studied a transient analysis of the thermo elastic contact problem for disc brakes with frictional heat generation is performed using the finite element analysis (FEA) method. The computational results are presented for the distribution of the temperature on the friction surface between the contacting bodies (the disc and the pad). Also, the influence of the material properties on the thermo elastic behavior, represented by the maximum temperature on the contact surface is investigated by comparing different types of disc brake materials. Thermo-Elastic Instabilities (TEI) at the disc brake rotor surface. Localized TEI act at the friction ring surface generating intermittent hot bands around the rubbing path which may in turn leads to the development of so-called hot spots.

II. SOLID VS VENTILATED DISC BRAKES

The disc brake is a device used for slowing or stopping the motion of the vehicle. Friction between the brake pad and disc causes the vehicle to slow or stop. The heat generated during brake application has to be dissipated easily. If the heat generated due to friction was not dissipated, it leads to thermal instability, brake fade and sometimes may loose stopping power. The main focus is to minimize the thermal stress and to select the type of disc (either solid or ventilated type disc brake) that suits for the application and to select the best suited material.

The rotor disc may be either ventilated or solid. Ventilated disc brakes are like two flat discs put together, one on top of other, with gaps for flow of air. Compared to solid disc the ventilated disc has more heat dissipation capacity. Most of the two wheelers and four wheelers front brakes have vents for easy dissipation of heat.

But in heavy structures like wind turbines the diameter of the disc will be more and pressure on the disc during braking will also be more on the disc brake. In such large diameters, if ventilated or drilled discs are used it may be lead to formation of hair like cracks near the vents and holes which may sometimes lead to total failure of the disc brake system. So in wind turbines, compared to ventilated disc brakes it is better to use solid type disc for braking system, as safety always comes first.

III. DISC BRAKE PROBLEMS

In the course of brake operation, the heat energy generated due to friction is dissipated mostly in to pads. Sporadic uneven temperature distribution on the components can induce severe thermo elastic distortion of the disc. Due to this thermal distortion on a flat surface of a rotor disc, deformation takes place which leads to thermo elastic transition. On the other hand due to the advancement behaviour of the sliding system crosses limits as a result of which a sudden change in contact conditions occurs as the result of instability. This invoke,

- Transient thermo elastic distortion of the disc due to uneven temperature distribution.
- Localized bulging due to frictional heating.
- Contact pressure increases due to localized bulging.
- Local hot spots due to frictional heating.
- Thermal crack on the disc.

MATERIAL SELECTION

Aluminium Alloy Series		Main Alloying Element	Strength	Density (g/cc)	Elastic modulus (Gpa)	Yield Strength (Mpa)	Ultimate Strength (Mpa)	Thermal Conductivity (w/m-k)
1xxx	1100	None (pure Al)	Low	2.71	69	115	69-186	218
	1060			2.705	69	90		230
	1050			2.705	71			222
2xxx	2014	**Cu**	**High**	2.8	73	290	**186-427**	131
	2024			**2.78**	**73**	**325**		**151**
	2219			2.84	73	185		121
3xxx	3003	Mn	Medium	2.73	69	145	110-283	159
	3004			2.72	69	200		163
	3105			2.72	69	150		172
4xxx	4032	Si	Medium	2.68	79	315	172-379	138
5xxx	5005	Mg	Medium	2.7	69	150	124-352	200
	5052			2.68	70	215		138
6xxx	6061	Mg-Si	Medium	2.7	69	145	124-400	154
	6063			2.7	90	69		193
7xxx	7075	Zn	High	2.81	72	505	221-607	130

From the above table 2xxx series aluminum has more desirable properties compared to other series of Al alloys. Strength of 2xxx and 7xxx series Al alloys is very high but the atmospheric corrosion resistance for 2xxx is very high when compared to 7xxx series alloy due to clad of 2xxx series alloys.
The ultimate tensile strength and thermal conductivity is also considerably suitable for required barking system.
Due to high yield strength 2xxx series will have high strength to weight ratio. With the application of pressure on that material of disc the deformation rate can be reduced and life of disc can be increased.
Among the materials from 2xxx series 2024-T4 aluminium alloy has been selected for analysis due to its less density, high yield strength and thermal conductivity of the material. The casting ability of 2024 aluminum alloy is also high.

IV. BRAKING REQUIREMENTS

- During emergency conditions the brakes must be strong enough to stop the vehicle with in the short period of time.
- At the time of applying brake the heat energy generated should be dissipated irrespective of the brake location.
- The brake pad area must be ample to govern the temperature rise.
- The brakes must have well anti fade away characteristics i.e. their efficiency should not diminish with constant prolonged application.
- The brakes ought to have well anti wear properties.

Classification of Brakes:

- Mechanical brakes
- Electric brakes
- Pneumatic brakes
- Hydraulic brakes

The mechanical brakes deliberating to the method of acting force may be divided into the subsequent two groups:

1. Radial brakes.
2. Axial brakes.

1.Radial brake:

The pressure acting on the brake drum will be in the radial direction. It is again divided in to external brakes and internal brakes.

2 .Axial brakes:

The pressure acting on the brake will be in the axial direction only. It is divided in to Disc brakes and Cone brakes.

Disc Brake

Disc brake use hydraulic pressure to lock brake pads counter to ta rotating disc called rotor. To stop the blades (Propeller) rotating too rapidly Disc Brakes have been used in wind turbines. They are fixed inside a nacelle (the square shaped case after the propeller that comprehends the gear box and the generator)

Principle:

The main principle involved during braking is, the applied energy (Pressure) acts on the brake pads which comes in contact with the moving disc called rotor. At this instant of time due to friction between the pad and the rotor the relative motion is constrained.

The main components of Disc Brake are:

- Rotor ,which is attached to the hub
- Brake pads
- Caliper, which comprises the piston

Fig-1: Disc brake with two calipers in Wind Turbines

V. Importance of braking in Wind Turbines

Wind is the rejoinder of the atmosphere to uneven heating conditions. Local topography (mountains) can augment or restrict the natural wind flow. Solar radiation differentially captivated by earth surface rehabilitated through convective procedures due to temperature difference of air motion.

The importance of wind turbines in generating electricity has been increasing due to requirements of clean and renewable energy. As wind is renewable energy, getting the utmost possible output from a given set up has become more and more important.

The amount of useful energy that can be generated from a wind turbine set up is proportional to the area which the blades of the wind turbines will swish. Due to this, the size of the wind turbine structures has been increasing steadily. But this place more loads and stresses on the power transmission components like brakes in specific. Brakes for wind turbines call for higher cycle rates, higher loads, and greater reliability and often in more compact structures than those on orthodox industry equipment. Consider, too, that they must operate automatically in installations that are generally unmanned and often in isolated areas that makes access for maintenance both difficult and costly. They must operate reliably in some of the most stimulating environmental conditions often subject to immoderations of humidity or temperature. They must ensure absolute reliability when located in areas as diverse as offshore situates in salt atmospheres or desert situates subject to dust.

Brakes play a dynamic role at various positions of a wind turbine. Irrespective of size, a turbine structure will require rotor brakes, yaw governor brakes and blade pitch governor brakes all with precise design. Most turbines have an anemometer on them to measure the wind speed. If the wind speed increases above safe level, the brakes come on automatically and bring the propellers to a halt. When generator failure happens, to stop the motion of the rotor and to prevent the over speeding causing disasters brake should be applied to shutdown the wind turbine.

VI. Conclusion

Disc brake design plays an important role in transfer of heat. In wind turbines, disc brakes experience both thermal and structural loads. By analysis there is a scope for improvement of life assessment of disc brake. There is also scope for reducing the weight by comparing the disc brake with two different materials so that thermal stresses can also be predicted.

VII.References

[1] K.Wang, M.O.L.Hansen, and T.Moan, “Dynamic analysis of a floating vertical axis wind turbine under emergency shutdown using hydrodynamic brake”, Energy Procedia 53 (2014) 56 – 69.

[2] Frank Jepsen, Anders Soborg, and Zhenyu Yang, Disturbance Control of the Hydraulic Brake in Wind Turbine, Energy Conference and Exhibition (EnergyCon), IEEE International.

[3] S.P.Jung,T.W.Park,J.H.Lee,W.H.Kim,andW.S.Chung,FiniteElement Analysis of Themalelastic Instability of Disc Brakes (2010)VolIIWCE2010.

[4] H. Mazidi, S.Jalalifar, S.Jalalifar, J. Chakhoo, Mathematical Modeling of Heat Conduction in a Disc Brake System During Braking, Asian journal of Applied Science 4(2): 119-136, 2011.

[5] Cueva. G, A. Sinatora, W. L. Guesser, A. P. Tschiptschin, Wear resistance of cast irons used in brake disc rotors, WEARS, **255**, 1256-1260 (2003).

[6] LEE, K. AND BARBER, J.R. Frictionally-Excited Thermo elastic Instability in Automotive Disk Brakes, ASME J. Tribology, vol. 115, page 607-614, (1993).
[7] Daniel Das. A, Christo Reegan Raj. V, Preethy. S, Ramya Bharani. G Structural and Thermal analysis of disc brake in Automobiles (2013).
[8] M. Saran Theja, M. Vamsi Krishna, Static and Thermo-Mechanical Analysis of Disc Brake (2013).
[9] Guru Murthy Nathi, T N Charyulu, K. Gowtham, P Satish reddy Coupled Structural / Thermal Analysis of Disc Brake(2012)
[10] V. Chengal Reddy, M. Gunasekhar Reddy, "Modeling and Analysis of FSAE Car Disc Brake Using FEM" International Journal of Emerging Technology and Advanced Engineering, Vol.3, PP 383-389, 2013
[11] Eltoukhy.M. M, S.Asfour, M.Almakky. M, C. Huang, Thermoelastic Instability in Disc Brakes: Simulation of the Heat Generation Problem (2006).