Static Structural Analysis of a Flywheel-Shaft Assembly using Shrink Fitting for Static & Dynamic Conditions

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Abstract— In this study I have analysed the behaviour of rotating Shaft/ Heavy Disk, due to centrifugal force & contact pressure due to shrink fit via Finite element method and analytical analysis. I also found in my study there is risk and challenge mitigation is always there because to mount flywheel over a shaft we require need to heat flywheel to achieve the required shrink for mounting the flywheel on the shaft higher temperature is required which leads to temperature gradient and control method of doing this activity but at the same time higher deformation which then tends to nonuniformity in the flywheel inside diameter so required uniform contact between shaft and flywheel is difficult to achieve, higher shrink also increase the tangential stresses in the flywheel which leads to failure of the flywheel and vice versa also higher runaway or maximum speed of rotor leads to a gap between shaft and flywheel. To achieve all this required parameter, I have done so many permutations and combinations then I have concluded with a solution using the finite element method which is further validated by hand calculation. I have solely focused in centrifugal stresses and total radial deformation on all type of heavy disc/flywheel whose results are validated by analytical calculation and finite element method results. I have also studied the critical speeds, as we know a rotor spinning /rotating generates a gyroscopic couple, which is an end product of polar mass moment of inertia and the angular velocity which is resulting the couple in the direction following the right-hand cork screw rule. Inertia and gyroscopic torques or couple makes the bending moment jump along the heavy disc or flywheel.

Keywords: Rated speed, runaway speed, standstill condition, plasticity, plastic strain, heavy disc or flywheel, FEM analysis, CATIA V5-6 R2017

I. Introduction

In this research paper study is on the optimization with the changes proposed in the geometry of shaft and Heavy Disc or Flywheel so that heavy disc remain intact with rotor shaft at maximum speed and electrical failure torque due to shrink/contact pressure defined in the interface region.

The FEA model construction of flywheel is considered in geometry simple as a cylindrical disc type construction of a solid material, alternatively we have worked on spoked construction which is a hub type design with rim connected by spokes or arm small or big discs of hollow in cross construction depends on the energy requirements and size of the disc varies the geometry changes to flywheel of central hub with peripheral rim connected by webs and to hollow wheels with multiple arms.

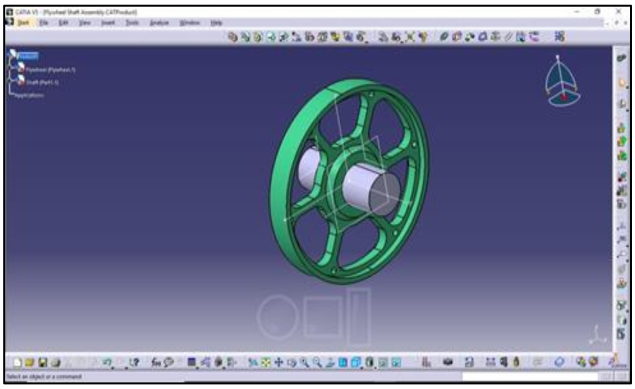

Fig. 1: Arm Type Heavy Disk

A. *Stress*

In a Heavy disc or a flywheel the point of interest is the inner diameter whereas the stress is always being maximum which results in a failure of a heavy disc a typically the hoop stress and tangential stress at that point from where the crack start propagating and leads to fracture fragments which than explode leads highly dangerous consequences, We know the forces which causes the stresses are a function of a rotational speed further instead of checking the stresses ,the maximum speed at which the stresses initiate the critical value shall be determined and a safe operating speed shall be evaluated or specified based on the safety factor.

B. *Flywheel Effect*

The heavy disc attached to a rotating rotor called as flywheel which smooths out power from turbine to a generator. The inertia of the heavy disc controls the fluctuation in the variable speed of the large rotor which in turns stores the excess energy for intermittent use. In hydrogenator fluctuation occurs in the rotor due to water flow (incoming the runner blade or bucker and leaving the runner). We also knew that Heavy disc energy storage uses the turbine to rotate at high speed so the mechanical power is transformed into electrical power and stored and when necessary, flywheel drives generator to generate the power.

II. Problem Statement

I have selected the combination of a rotating shaft & a flywheel for my dissertation work. Here a flywheel will be shrinking fitted over a rotating shaft. In order to complete the analysis requirements, this flywheel-shaft assembly will be analyzed for below cited conditions-

- Standstill condition (flywheel & shaft both at rest).
- Rated speed (Rated RPM) of the shaft in any given practical application (flywheel & shaft both rotating).
- Runaway speed (Runaway RPM) of the shaft for the same practical application (flywheel & shaft both rotating).

Now every condition would be governed by calculation of some process parameters on the basis of which any conclusion will be drawn hence for each & every condition some important process parameters would be evaluated. These parameters include-

- Hoop stress.
- Type of fitting (Shrink fitting).
- Radial Interference.
- Torque Capacity.
- Strain

III. ANALYSIS OF FLYWHEEL-SHAFT ASSEMBLY

A. Steps in ANSYS analysis

- For analysis purpose Gray Cast Iron will be used & the properties of this material are as follows-

Parameter	Values
Young's modulus	$1.1*10^5$ MPa
Poisson's ratio	0.28
Density	7200 Kg/m^3
Tensile strength ultimate	240 MPa
Shear Modulus	$429.69*10^2$ MPa
Bulk Modulus	833 MPa

Table 1: Properties of Gray Cast Iron

- Start the analysis process of the 3D model in ANSYS by selecting static structural module.
- Select flywheel-shaft assembly material grey cast iron.
- Apply material properties.

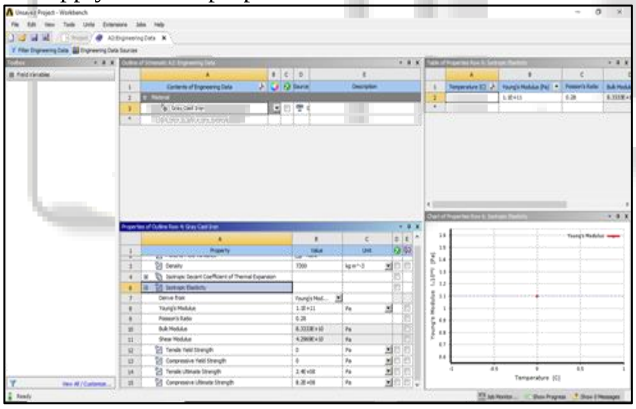

Fig. 2: Applying material properties

- Define contact between leaves of flywheel-shaft assembly

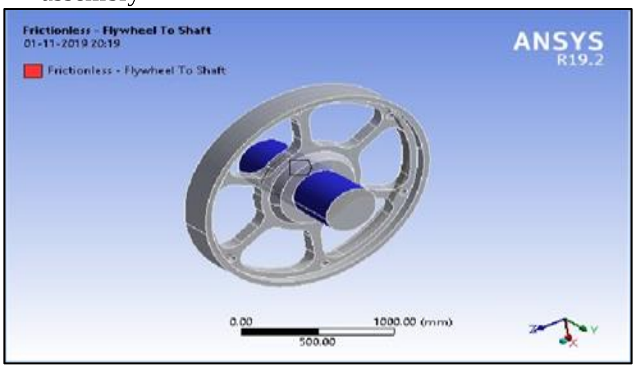

Fig. 3: Defining contact between parts

- Create meshing of flywheel-shaft assembly.

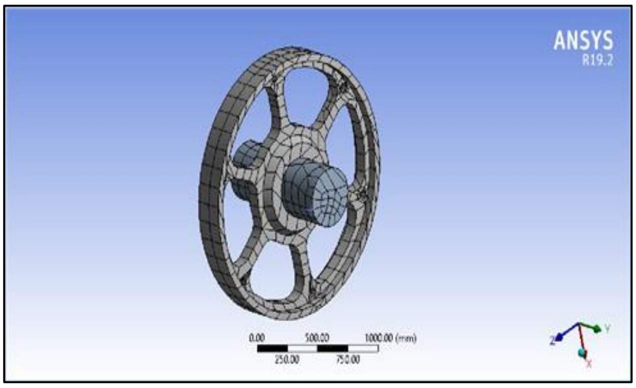

Fig. 4: Creating mesh for the components

The process of meshing is known as the technique to divide the components in numerous small parts which may be two dimensional, three dimensional & one dimensional depending upon the need & components. All the parts consist of elements & nodes. As can be seen in the figure that total number of elements developed here are 2137 & and total number of nodes developed here are 6765.

- Apply boundary condition

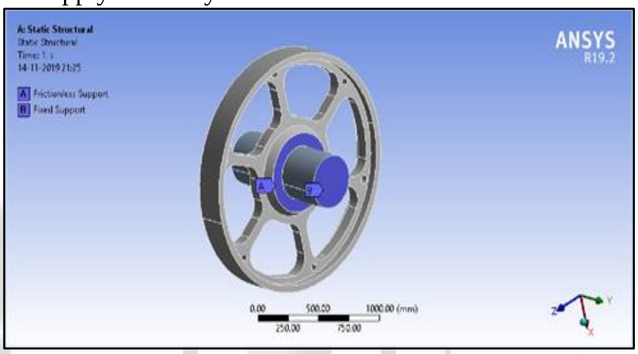

Fig. 5: Applying boundary condition

- Run the analysis

B. Get the results.

Results Analysis at Standstill Condition

In order to analyse the behaviour of flywheel-shaft assembly in standstill condition hoop stress and total deformation have been evaluated as these two are the primary factors which will affect the given model during processing.

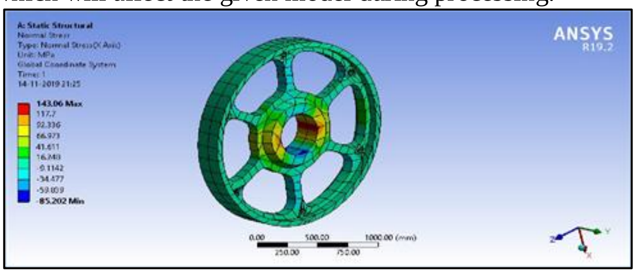

Fig. 6: Hoop stress

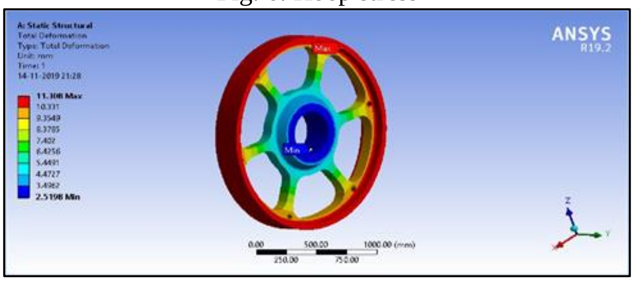

Fig. 7: Total deformation

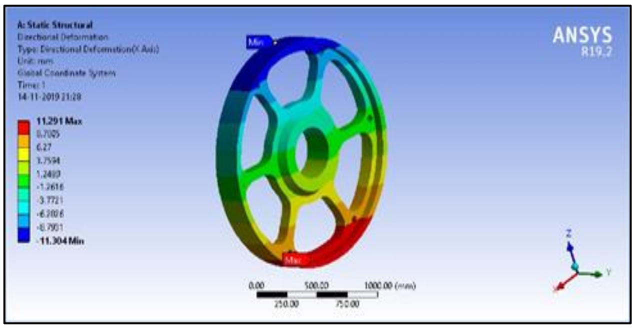

Fig. 8: Directional deformation

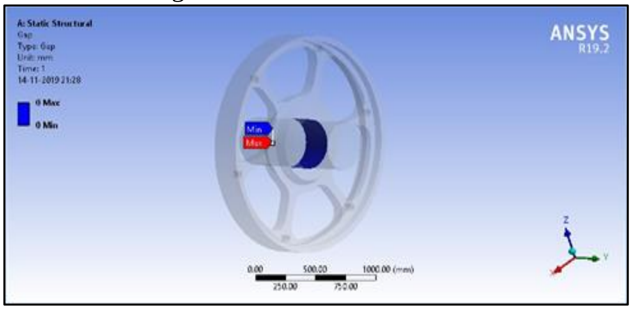

Fig. 9: Contact gap

C. Result Analysis Due to Rotation

For this particular study 10 different rotational velocities have been provided as the boundary condition & the resultant normal stress, total deformation, contact pressure & contact gap values have been calculated using ANSYS simulation & these values are being compared with mathematically calculated values of normal stress. Results at 200 RPM rotation are presented here for reference.

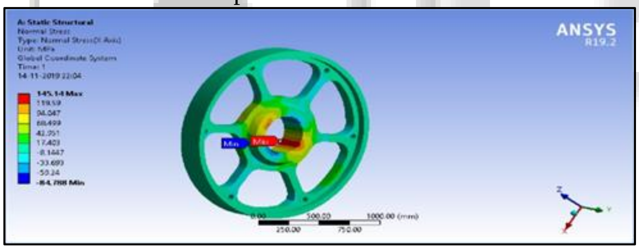

Fig. 10: Normal stress

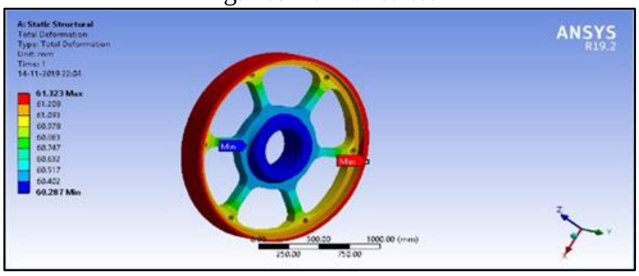

Fig. 11: Total deformation

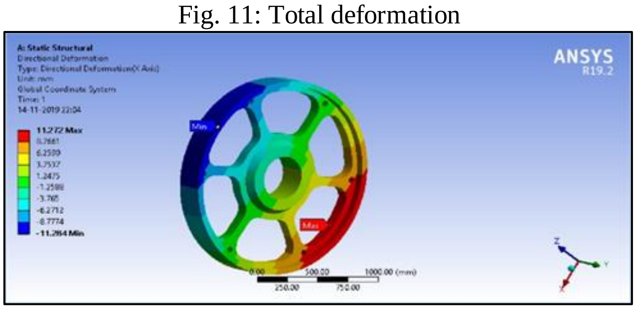

Fig. 12: Directional deformation

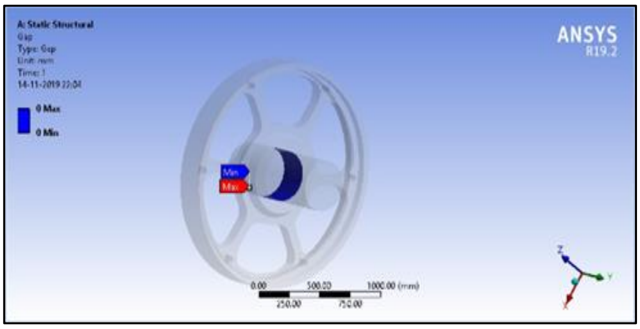

Fig. 13: Contact gap

All this data is now being represented in form of a table for further reference.

S. No.	RPM Value	Process Parameter	Numerical Value
1	200	Hoop Stress	145.14 MPa
2		Total Deformation	61.323 mm
3		Directional Deformation	11.272 mm
4		Contact Gap	0
5	400	Hoop Stress	146.93 MPa
6		Total Deformation	61.571 mm
7		Directional Deformation	11.265 mm
8		Contact Gap	0
9	600	Hoop Stress	149.9 MPa
10		Total Deformation	61.984 mm
11		Directional Deformation	11.253 mm
12		Contact Gap	0
13	800	Hoop Stress	154.07 MPa
14		Total Deformation	62.563 mm
15		Directional Deformation	11.235 mm
16		Contact Gap	0
17	1000	Hoop Stress	159.43 MPa
18		Total Deformation	63.31 mm
19		Directional Deformation	11.217 mm
20		Contact Gap	0
21	1200	Hoop Stress	178.63 MPa
22		Total Deformation	64.227 mm
23		Directional Deformation	11.204 mm
24		Contact Gap	0 mm

Table 2: Result Table Due To Rotation

IV. RESULT ANALYSIS

A. Normal Stress Distribution

Results of the normal stress distribution reveal that as we increase the rotational speed or rotational velocity of the shaft, maximum normal stress developed in the flywheel is also increasing & the value of average normal stress is also increasing. The same may also be shown through a graph. But there is an eye-catching fact that although the values are showing that if one increases one process parameter then other parameter is also increasing yet this increment is very less which can approximately equal to the stress induced at standstill condition till 600 RPM. After this when we further increase rotational velocity, there is significant increment in maximum normal stress value.

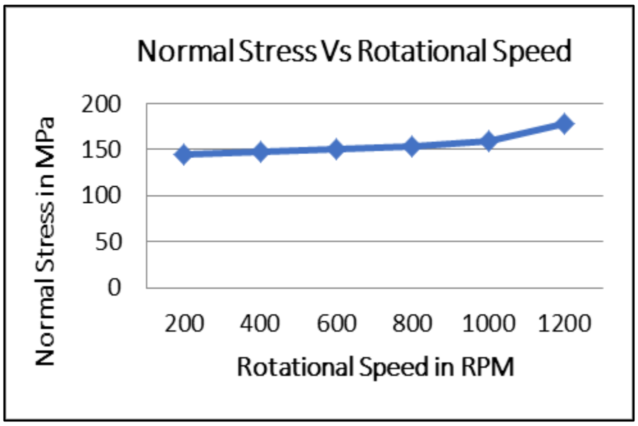

Fig. 14: Normal stress distribution

B. Total Deformation Distribution

as we increase the rotational velocity of the assembly, total deformation shows a positive increment for both minimum & maximum total deformation distribution although this increment is very large which may be assumed approximately linear just like normal stress distribution. The graph of this particular distribution will again show an approximately linear variation.

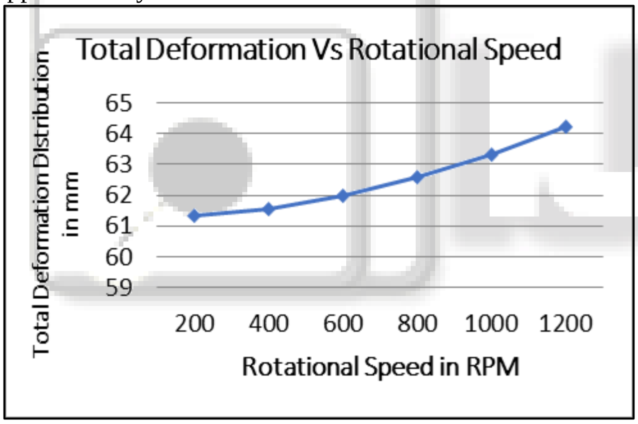

Fig. 15: Total deformation distribution

C. Directional Deformation Distribution

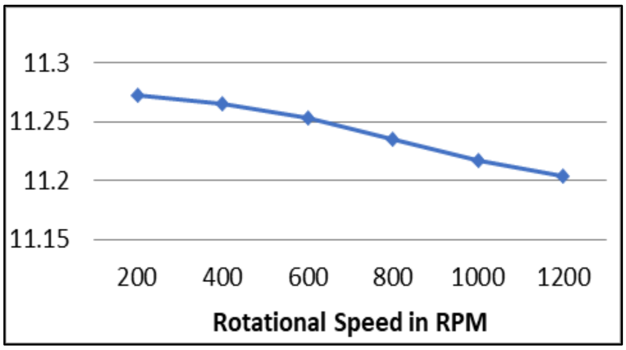

Fig. 16: Direction deformation distribution

D. Contact Gap Distribution

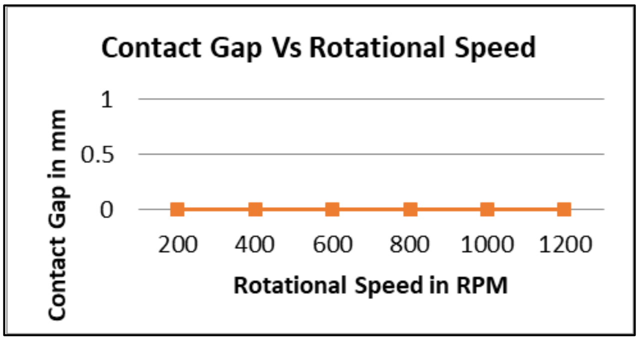

Fig. 17: Contact gap distribution

one can see that here flywheel shaft assembly has been analyzed for different RPM values & the observations have been made. All these observations are now being represented in form of a comparison chart. These comparison charts will lead us to validate & observe the behavioral changes which may or may not occur as the process parameters are varied. In order to observe the behaviour of the assembly two different types of charts will be presented here.

V. CONCLUSIONS

This static structural analysis of Gray Cast Iron Flywheel-Shaft assembly draws numerous conclusions some of which are listed below-

- First & foremost important conclusion which one can draw from this study is that Shrink fit may be considered as the best type of interference fit as it has lower energy losses.
- When we see the variation pattern of normal stress, we can see that there is a large difference between the maximum & minimum values of normal stress in both the standstill & running condition. This is due to the large amount of surface area of flywheel which is in contact with the shaft. Because of this large difference there may be some regions where abrupt changes in normal stress occur & this can cause severe damage to the performance of the assembly.
- Upon observing the pattern of total deformation one can see that for the given inputs this assembly restricts itself to deform much. There is very less deformation which in millimeters & it is in completely elastic regions. There is no plastic or permanent deformation in the assembly hence the assembly may be used for higher rotational velocities also.
- If we see the pattern of directional deformation variation, its variation upon increasing the rotational velocity is showing a specific pattern. Its uppermost part is getting deformed to the minimum value & lowermost part is getting deformed to the maximum value
- When we observe the pattern of contact gap with respect to rotational velocity, it also shows negligible variation if we increase the rotational speed or velocity. Again, we can conclude that contact gap is independent of rotational velocity & it only depends on material properties & shape & size of the component.

– For the given inputs there is no slippage between flywheel & shaft.

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