ANALYZE EFFECT OF FILLET ON POLYGONAL SHAFT AND DISC ASSEMBLY

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Abstract - The polygonal shaft and disc has its own advantage of assembly with little or no interference to be used for the assembled components, in addition to very less stress concentration. This method can be very beneficial to heavy duty applications such as turbo machinery. It is possible to transfer higher torque smoothly with polygonal shaft. Usually loboid shaft cross section and identical shaped bore is used, however keeping the sides flat with fillet at the corners will give reasonable results. The advantage of fillet over lobed profile is that the former profile takes less effort to manufacture. This paper gives an idea about the effect of fillet radius in polygonal shaft-disc assembly. An attempt is made to test the triangular profile shaft cross section with different fillet radius at the corners. The analysis reveals that as the fillet radius increases, the stress decreases drastically in addition to healthy contact pressure and increased stickiness for tighter connection between the shaft and disc assembly.

Keywords - Polygonal Shaft, Polygonal Disc, Fillet Radius, Turbo Machine.

I. INTRODUCTION

Polygonal method of assembly is suitable for high and cyclical loading at higher speeds of rotation. It is even applicable for fixed and sliding couplings. In every transmission system the enhancement of efficiency has always been a never-ending pursuit. It is not just spinning, but how proficiently it spins is the important factor. For example, if we want to connect a driving element like motor directly to the output end of the machinery, then there would hardly be any concern about the efficiency loss. However, due to space constraints as well as machine profile, transformation of revolving speed, variation in axial direction, etc., are unavoidable in almost all machineries.

A novel idea presented by L. Haugen, Robert King and Jeff Schmidt on Polygon Coupling for rotor [1], the shaft has a polygonal cross-section. The rotor includes a corresponding polygon plug configured to be placed in the bore of the shaft. Additionally, the rotor may include a polygonal cross-section, and the shaft may include the polygon plug configured to be placed in the bore of the rotor. The plug of the shaft is split so that when the fastener is inserted into the passage the plug expands against the side wall of the bore thereby creating an interference fit between the shaft and the rotor. This method gives an idea that the polygonal coupling can be employed for assembly of components with little or no interference.

In turbo machines, the typical fit between the rotor and shaft using shrink fit method to provide interference may build up higher residual stresses throughout the component bore. Residual stress may be desirable or undesirable. For instance, laser peening imparts deep beneficial compressive residual stresses into components of metal such as turbine engine fan blades but unintended residual stress in a designed structure may cause it to fail prematurely. For rotor assembly, uninvited residual stress is prone to happen if employed shrink fit is beyond the requirement. Such higher residual stresses can be curbed with use of polygonal coupling method, since it employs small or no interference. Polygonal method proves beneficial for assembling the components in one go with less time unlike shrink fit method wherein, the components to be assembled on the shaft has to be done individually, which takes lot of time and effort.Polygonal method proves highly reliable against fatigue breaks in addition to ease of assembly and disassembly. Also, it has greater capacity for torque than any other shaft attachment. The polygonal connections can be more advantageous than conventional method because of lower stresses and the lack of stress concentrations [2].

Precise manufacturing of the polygonal profile is the backbone for efficient torque transmission and retain healthier contact between the assemblies. In a research paper by A. Kyusojin, H. Inada pertaining to “Lapping High Precision Polygonal Shaft”, a finishing method to improve roundness accuracy of cylindrical shafts and holes for the multifaceted profile to keep tighter tolerance with respect to surface finish for enhanced efficiency is analyzed [3]. A study on steel made polygonal couplings, with trochoidal three-lobe profile aimed to highlight the contact stress and strain state of shaft-hub interface is presented by Roberto Citarella and Salvatore Gerbino [4]. Polygon with lobed profile is generally used to assemble the component but due to its high precision demand and tighter tolerance, an attempt is made to use fillet at the corners while keeping the sides flat and is discussed herewith considering three sided polygon with different fillet radius.

II. METHODOLOGY

2.1. Modeling

A simple shaft and disc approach is considered for the study. The test specimen with suitable size for three sided polygon and different fillet radius is modeled using ANSYS® software. One of such model having 5mm fillet is shown in Fig. 1.

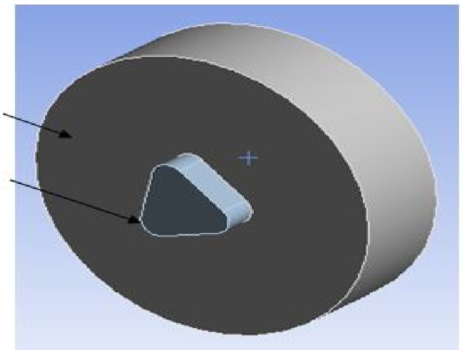


Fig.1. Polygon disc hub and polygon shaft assembly

2.2. Analysis

Analysis is carried out in ANSYS® software package. Static structural analysis in workbench is performed wherein, the material normally used for heavy duty applications is considered for rotor (disc in this case) and shaft. For most applications, high-strength alloy steel is preferred for the rotor material. Similar material is chosen for disc having better strength and appropriate yield strength for shaft material is considered. The assembled component as shown in Fig. 1 is then imported in static structural environment. Proper material is selected for the respective component. Appropriate contact constraints for shaft and disc are applied. Standard meshing is considered for the components to be analyzed. Fine meshing is used as shown in Fig. 2 for better accuracy of results.

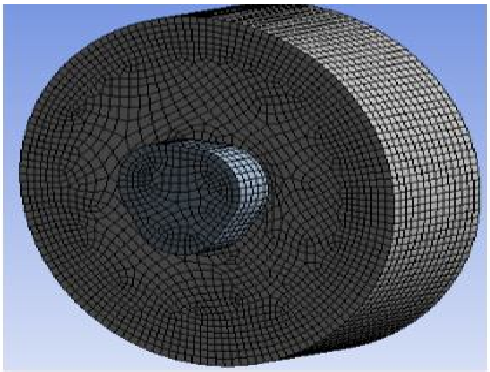


Fig.2. Fine Meshed Assembly

Essential boundary conditions pertaining to assembly involves the disc and shaft to be constrained axially in addition to rotational constraints. Shaft motion is constrained using two nodes i.e. one node to prevent axial motion and the other node to take care for rotation. Similar condition is employed to inside surface of the disc for axial and rotational constraints. Loading involves rotating the disc at certain rpm. After applying proper boundary conditions and loadings for the assembly as shown in Fig. 3, the model is solved.

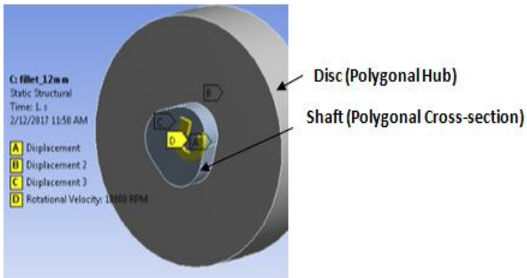


Fig.3. Boundary conditions and loadings

The flowchart for the steps followed during analysis is shown in Fig.4.

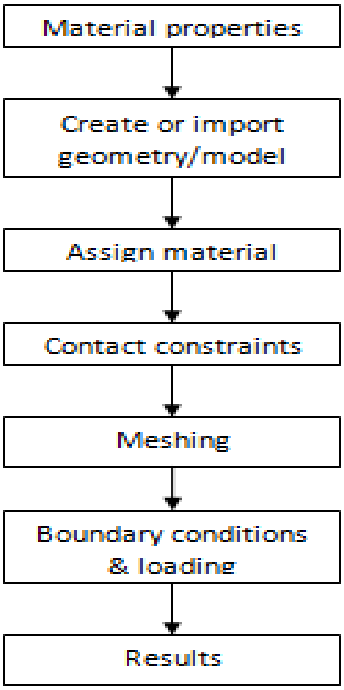


Fig.4. Steps in Ansys

In a similar manner, the procedure as discussed is applied to different fillet radius for the three sided polygonal assembly i.e. modeling polygonal geometry with different fillet radius and performing the analysis using ANSYS® software package and carrying out the steps as seen in Fig. 4. Polygonal assembly for different fillet size is tested to check the feasibility of the design constraints. Different fillets having the radius of 2mm, 5mm, 10mm and 12mm based on the geometry is modeled and analyzed. Fig. 2 depicts one of such polygon assembly having fillet of 12mm radius. Based on the model the fillet can vary accordingly and decision for appropriate fillet should be made based on reduced stress levels and healthier contact connection.

III. RESULTS AND DISCUSSION

Table 1 shows the result for the effect of different fillets with respect to maximum stress levels, average contact pressure and maximum deformation for the polygonal assembled components.

Fillet Radius (mm)	Maximum Equivalent Von-Mises Stress (Mpa)	Average Contact Pressure (Mpa)	Maximum Deformation (mm)
2	1102.30	717.61	0.049
5	881.99	593.44	0.046
10	833.31	424.54	0.042
12	773.54	366.33	0.039

Table 1. Effect of Fillet Radius on Performance

The principal attention is to analyze the equivalent Von-Mises stress and contact pressure between shaft and disc for safe operations. Reduced stress levels and healthier contact pressure is the deciding criteria. From Table 1, it is evident that with increase in fillet radius the stress decreases appreciably for 12mm fillet compared to 2mm fillet radius. Fig. 5 shows the Von-Mises stresses for 2mm and 5mm fillet radius respectively. Similar contours with reduced stress levels are obtained for 10mm and 12mm fillets.

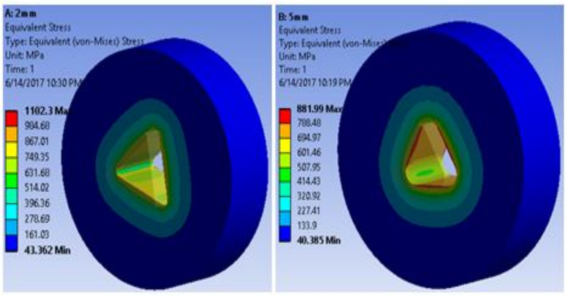
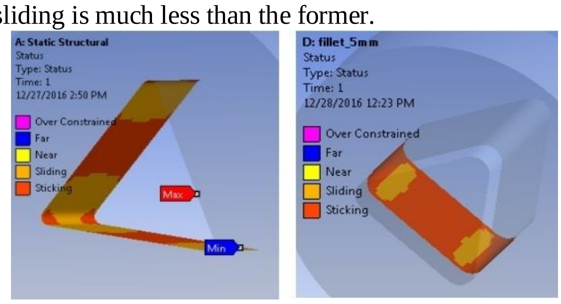


Fig.5. Equivalent Von-mises stress (2mm & 5mm fillet radius)

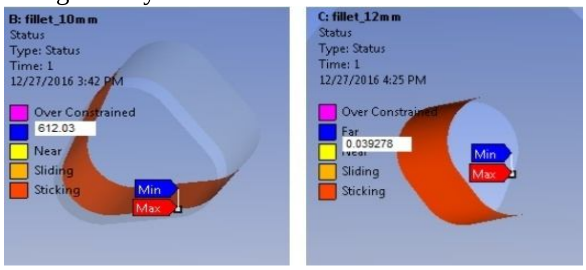
Also, as seen in Table 1, with increase in fillet radius the average contact pressure seems to go down, however decision should be made based on the required average contact pressure and healthier contact status. The contact status reveals that with increase in fillet radius stickiness is more i.e. healthier contact prevails. As seen from Fig. 6, the contact status for 2mm fillet radius is sliding for nearly half of the contact zone whereas for 5mm fillet radius, the sliding is much less than the former.



(a) (b)

Fig. 6. Contact status (a) 2mm fillet radius (b) 5mm fillet radius

With increased fillet radius the stickiness is dominant over the entire contact zone. From Fig. 7 for 10mm and 12mm fillet respectively, absence of sliding region is evident i.e. the complete contact region is highly sticky which means strong connection between the polygonal disc and shaft exists. For 12mm fillet as seen in Table 1, the stress is approximately 10% less than the 10mm fillet; however contact pressure seems to be better for the 10mm fillet. Therefore, the decision should be made based on the stress levels and required average contact pressure. If both the criteria show similar results then the stress concentration should be checked which will be lower for higher fillet geometry.



(a) (b)

Fig.7. Contact Status (a) 10mm fillet (b) 12mm fillet

With increase in fillet radius the deformation is decreasing which shows a positive sign. There is approximately 20% reduction in deformation for 12mm fillet relative to 2mm fillet radius.

CONCLUSIONS

The analysis for three sided polygonal disc and shaft assembly with different fillet radius at the corner reveals that higher the fillet radius higher is the effectiveness and better the performance with reduced stress levels besides healthy contact status and reduced deformation. Even though the contact pressure reduces with increase in fillet radius, the stickiness between the components being assembled helps to decide the optimum fillet to be chosen. It may please be noted that optimum fillet should suffice the work because with continuous increase in fillet, the required contact pressure shall be a concern. Hence, it can be concluded that the increase in fillet radius helps to achieve better design aspects.

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