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Simulations of Interference and Interfacial Pressure for Three Disk Shrink Fit Assembly

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ABSTRACT

In this study, three disk shrink fit assembly (solid shaft-sleeve-holder) was modeled by finite element method to determine the effects of the interference or shrinkage allowance on interference or interfacial pressure. Stress distributions along the thickness were plotted. The highest stresses were observed at the inner surface of the holder. Solid shaft had a uniform stress distribution. Sleeve and holder had non uniform stress distributions, which were higher at the inner surface and lower at the outer surface. Higher stresses can be reduced by lowering the interference between the sleeve and the holder. Equal interfacial pressures between disks can be accomplished using different interferences. It was concluded that finite element simulation is the only solution for complex geometry and various loading conditions.

Key Words: *Shrink fit, Shrink fit assembly, Interference fit, Three disk shrink fit.*

1. INTRODUCTION

Shrink fit assembly is a low cost joining method in which heat is used to produce a very strong joint between two metal components in order to transmit torque. The interference fit is produced by heating one of the components while keeping the other component cool for an easy assembly or vice versa. Heating causes the metal part to expand. Therefore, the other part can be easily inserted into the expanded part. Upon cooling, the expanded part shrinks back to its original size and frictional forces create a highly effective joint. These assemblies resist to relatively high pressures more efficiently and require less material than single disk. Because of these, compound or multiple disks are more applicable. This type of assembly is characterized by the amount of interference which provides an exceptional strength between the two parts. The resulting pressure between surfaces mechanically holds the two pieces together. Meanwhile, friction coefficients of two parts are important for creation of the frictional force between the two parts. Shrink fit method is more often used to replace the conventional mechanical fasteners. Common applications of shrink fit assembly are a shaft with a gear, a shaft with steering knuckle, a shaft with sleeve, tool holder assembly, ball bearing, roller bearing, wheels and bands for railway stock, turbine disks, rotors for electric motors roller etc. Shrink-fits must be properly designed and produced in order to achieve the desired performance. The stress and displacement equations as a function of geometry and pressures were first derived by French Engineer G. Lame' in 1833 [1, 2].

In this research, in an extension of two disk shrink fit assembly, three disk shrink-fit assemblies have been considered. These assemblies consist of three disks which are made of same or different materials. It is expected that three disk assemblies with different materials will have more application areas in industry in the near future. Product requirements (fatigue, corrosion, wear etc.) are not satisfied when the shrink is made by a single material. In order to have a desired shrink fit functionality, a proper understanding and solution methods are necessary. To the best of the authors' knowledge, no study has been found in the literature focusing directly on the three disk shrink fit assembly. In this study, the calculations of interfacial

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pressures and stresses for three disk shrink fit assembly were performed by finite element method (FEM).

2. THREE DISK SHRINK FIT ASSEMBLY

Shaft (disk 1) - sleeve (disk 2) - holder (disk 3) can be given as an example of this type of assembly as shown in Figure 1. The calculation of this type of fit is more complicated than the two disk shrink fit. It is possible to assemble the three disks at same time. However, it can be better to assemble them one by one in order to get better assembly control and accuracy. In this type of assembly, two disks should be assembled first and then third disk should be assembled to subassembly of disk 1 and 2 (Figure 2). It can be done by either heating disk 3 or cooling the subassembly. In this case, interfacial pressure is developed between disk 1 and disk 2. Due to the geometrical difference, disks will be under some stresses. After mating disk 3, additional stress will be generated for the assembly. The relationship between interference and interfacial pressures were determined by FEM.

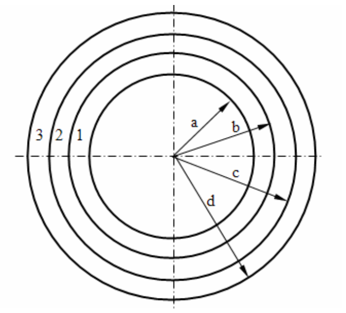

Figure 1. Three disk shrink fit assembly.

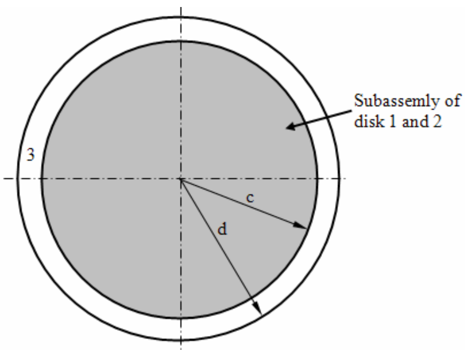

Figure 2. Final assembly of three disk shrink fit.

3. FINITE ELEMENT MODELING

Three disk shrink fit assembly with internal and external pressures and free end was considered. It is assumed that the end of cylinder is open and unconstrained. It means σ_z=0. Thus, the problem is in a condition of plane stress. One quarter of the assembly was modeled as shown in Figure 3 due to symmetry boundary condition. In the assembly, disk 1 can be hollow or solid based on application. For example, shaft is usually is solid for most of the shaft-gear assemblies. In this study, disk 1 was considered as solid. For the assembly, a=0 for solid shaft, b=20 mm, c=25 mm, and d=50 mm were assumed. XSYMM (degrees of freedom 1, 5, 6=0) and YSYMM (degrees of freedom 2, 4, 6=0) symmetry boundary conditions to the assembly were applied.

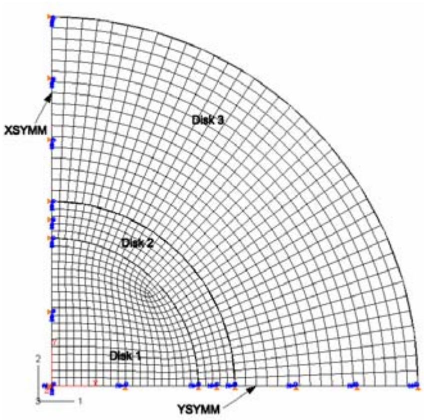

Figure 3. Finite element model of three disk shrink fit assembly.

In the models, the outer radius of disk 1 is a little bit bigger than the inner radius of disk 2 as same as disk 2 and disk 3. This means that there is over closures between the disks. This geometrical difference was modeled parametrically. In this way, interference can be changed easily in order to study the effect of interference on interfacial pressure. Three disks were meshed with a reasonable fine mesh.

Table 1. Elastic materials properties [4]

Material	E (GPa)	υ	σ_y (MPa)
Shaft (AISI 1045 Steel, as cold drawn, 32-50 mm round)	200	0.29	515
Sleeve (Copper, UNS C62300 (Aluminum Bronze 9%)	115	0.33	305
Holder (AISI 1045 steel, as cold drawn, 50-75mm round)	200	0.29	485

Continuum plane stress four node reduced integration with hourglass control (CPS4R) element was used. Since elements have only one integration point, they should be used with reasonable fine meshes [3]. Shaft, sleeve, and holder materials were considered as steel, bronze, and steel, respectively. Elastic properties were defined for materials which are summarized in Table 1 [4]. For each disk, two surfaces were defined as inside and outside surfaces. These surfaces were used to define the interaction between the surfaces. In initial step, surface to surface contact was defined with small sliding. An initial overclosure was also given at initial step. One of the surfaces was considered as a master surface and the other one was as a slave. A frictionless contact interaction property was defined. In the first step, the interference was resolved by automatic shrink fit with gradually remove slave node over closure. The interferences resulted in stresses and strains in a model as overclosures are resolved. Contact pressure (CPRESS) between disks was determined due to the initial overclosure. Because of the initial radius difference, the stress distributions on the disk were also calculated by FEM.

4. RESULTS AND DISCUSSION

Several interferences were simulated using the finite element model for three disk shrink fit assembly. It was mentioned that the analysis should be limited within the elastic deformation. The stress level of each disk should be within the elastic limit.

Five different interferences were studied using the parametrically developed finite element model. They were 0.005, 0.01, 0.015, 0.02, and 0.025 mm. In this study, same interference value was given to the disk pairs. It was quite possible to give different values for interferences. FEM results of 0.005 interference was given in Figure 4-7. Other interference values have also similar contours and behaviors. Figure 4 indicates the von Mises stress contours of the assembly. It is obviously seen that the contact surface regions have higher stress values. The distance far from contact surfaces have less stress values. Figure 5 shows von Mises stress distribution of solid shaft. It is clearly seen that solid shaft has a uniform stress distribution. The stress distribution of sleeve was shown in Figure 6. The inner surface of sleeve had higher stress than the outer surface. The stress decreased gradually from inner surface to the outer surface. Disk 3 or holder had a similar behavior for which higher stress was in inner surface than outer surface. The highest stress was developed at the inner surface of the holder.

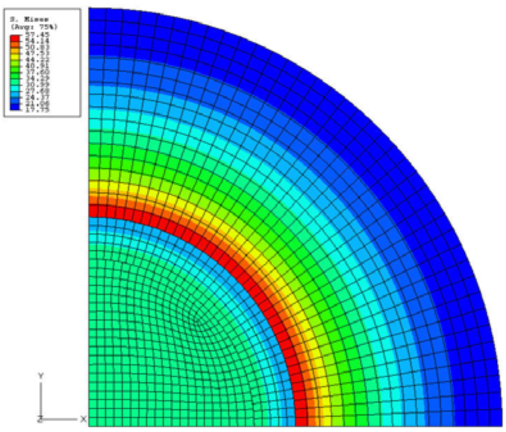

Figure 4. von Mises stress contours of three disks shrink fit assembly, MPa.

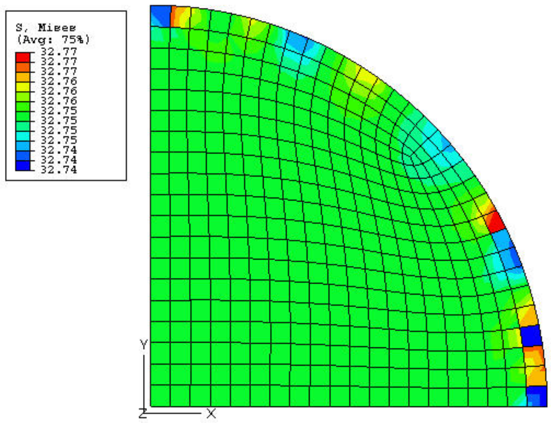

Figure 5. von Mises stress contours of solid shaft (disk 1), MPa.

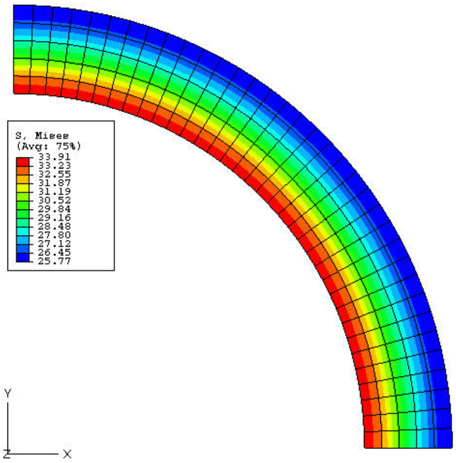

Figure 6. von Mises stress contours of sleeve (disk 2), MPa.

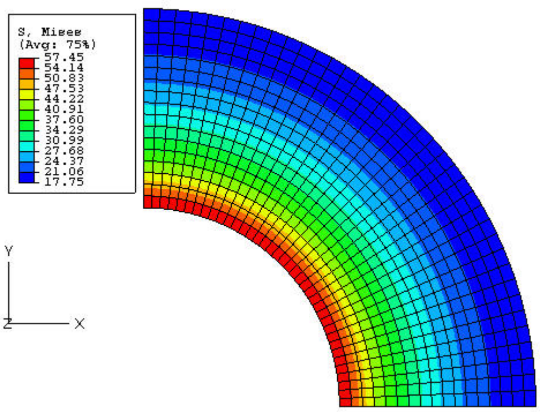

Figure 7. von Mises stress contours of holder (disk 3), MPa.

Interference created interfacial pressure between the disks. Based on the interferences, the interfacial pressure was calculated by using finite element software ABAQUS/Standard. Figure 8 indicates interference or shrinkage allowance vs. interfacial pressure. In Figure

8, the interfacial pressure between sleeve and holder is higher than between solid shaft and sleeve for the same interference. If same interfacial or interference pressure is desired, the interference between the sleeve and shaft should be smaller than the interference of solid shaft and sleeve. Figure 8 can easily be used to determine interferences in order to get same interfacial pressure between disks. For example; 52 MPa of an interfacial pressure between disks was required. The interferences were seen about 0.008 mm from the figure for solid shaft-sleeve and 0.01 mm for sleeve-holder. Simulation was performed for this case in order to see stress distribution on the disks. It was found that the interfacial pressure is about 45.8 MPa for sleeve-holder and 59 MPa for solid shaft-sleeve. The stress on the assembly was dropped from 114.88 MPa to 101.15 MPa. It is beneficial to have the same stress value for contact surfaces.

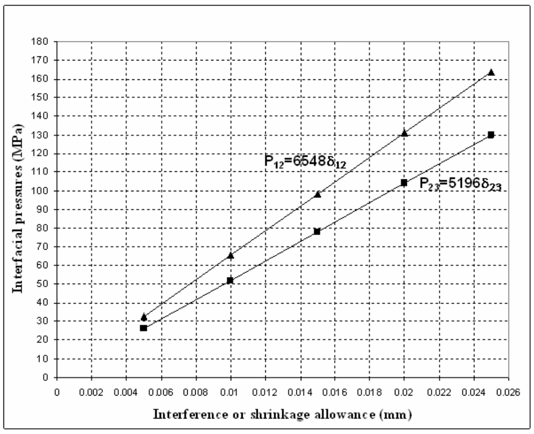

Figure 8. Interference or shrinkage allowance vs. interfacial pressure.

In addition to the interfacial pressure determination, von Mises stress distribution along YSYMM path was plotted in Figure 9. The figure indicates that the solid shaft had uniform stress distribution for all cases. The holder had a higher stress value at the inner surface. The interference increased the stress level linearly. It was also previously reported that the sleeve had a non linear curve and gradual decrease from inner surface to the outer surface. There was a big jump from sleeve to the holder. This stress increase can be decreased with smaller interference between sleeve and the holder. It is desired to have a uniform stress distribution along the disk. This can be accomplished by choosing the correct interference values.

In this study, external forces were not applied to the assembly. This model can also be easily used for complex geometries and complex loadings which cannot be solved analytically. It is also concluded that as long as in elastic deformation, three disk shrink fit assembly showed a similar trend for different interferences. Stress distribution can be adjusted by the interference value. Finally, the materials in shrink fit assembly should be checked for yielding.

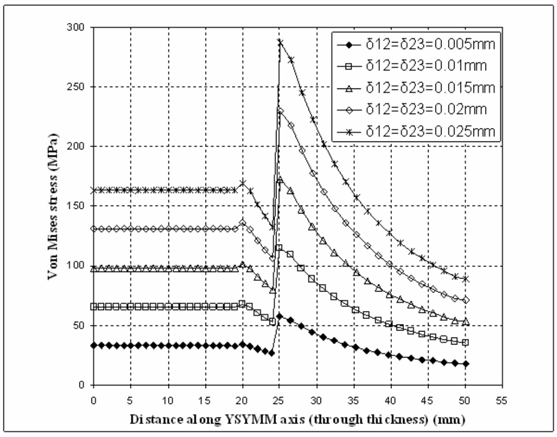

Figure 9. von Mises stress distribution along YSYMM axis (through thickness)

CONCLUSION

In this study, the effect of interference for three disk shrink fit assembly was simulated by commercially available finite element software, ABAQUS/Standard. Interferences or shrinkage allowances versus interfacial pressures and stress distributions through thickness were determined. Highest stresses were observed at the inner radius of the holder. Although the solid shaft had a uniform stress distribution for all cases, sleeve and holder had non uniform stress distribution. Sleeve had a higher stress at its inner surface than at its outer surface. There was a pressure difference which created additional stresses to the assembly at the inner and outer surfaces of the sleeve. This can be eliminated by making the interfacial pressures equal to each other between the disks. For complex geometry and loading conditions, FEM is the only solution. This model can be easily used to see the effect of geometry, load, and the materials.

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