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

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Abstract— Manufacturing & production industry is driven by heavy machinery being employed on large scale in order to meet the requirements of today's world. It has to carry out the production and manufacturing work day in and day out to match the ever-increasing demands from different sectors of the society. Here the machinery components need to work more than their rated capacity which sometimes causes severe failure and damages in components. Because of the large-scale competition which is present today in this industry, machinery components are not even allowed to fail. Rotating components play an important role in any machinery & they are very sensitive to handle. One key feature of the rotating components is how we connect two components which are in rotation with each other. Normally to connect two components we use fitting methods which are of mechanical type fitting & shrink fitting. In this dissertation we are analyzing the effects of shrink fitting between a shaft and flywheel when flywheel is mounted over the shaft using shrink fitting. The process parameters to be used will be hoop stress, radial interference, torque capacity and strain. The calculations will be done for standstill condition, rated RPM & runaway RPMs of the machinery components. The study would be completed in two steps. In first step, data will be calculated analytically using previous literature, empirical relations or mathematical calculations using formulae provided by reference books of respective subjects. Then in second step to validate the data a finite element simulation of the component assembly will be performed on ANSYS-19.0 workbench with 3D model of the assembly being created in PTC Creo 6.0.0.0/CATIA V5 R20. The results of both kinds of analysis will be compared with each other & hence a comparative analysis will also be performed.

Keywords: Flywheel-Shaft, Shrink Fitting, RPM

I. INTRODUCTION

Engineering fits are typically used as part of geometric dimensioning and tolerance when a part or assembly is designed. In engineering terms, the "match" is the clearance between mating elements, and the dimensions of this clearance determines whether the elements can pass independently from each different, or are then temporarily or maybe completely joined. Engineering suits are usually defined as a "shaft and hole" however aren't confined to simply round components. ISO is the across the world popular general for outlining engineering suits, but ANSI is regularly still utilized in North America.

Shrink fits serve the same purpose as force fits, but are achieved by heating one member to expand it while the other remains cool. The parts can then be easily put together with little applied force, but after cooling and contraction, the same dimensional interference exists as for a force fit.

Flywheel is a mechanical device specifically designed to efficaciously store rotational electricity (kinetic electricity). Flywheels withstand adjustments in rotational velocity by using their moment of inertia. The amount of energy stored in a flywheel is proportional to the rectangular of its rotational speed and its mass. The way to change a flywheel's saved energy without changing its mass is with the aid of increasing or lowering its rotational speed. Since flywheels act as mechanical strength garage gadgets, they may be the kinetic-power-storage analogue to electric capacitors, for example, that are a sort of accumulator.

II. REVIEW OF PAPERS

Nao-Aki NODA et al. [1] studied about steel conveying rollers used in hot rolling mills & the effect of heat on the surface of rollers. As the rollers are made up of steel, they are bound to get affected by the heat being generated in the immediate vicinity. They proposed a new kind of ceramic material to be used for rollers which isn't affected by heat. Their study indicated that maximum tensile stress occurs at the end of the sleeve at a certain amount of shrink fitting ratio. Process parameters to be used in this study were shrink fitting ratio, fitted length, material difference, radius curvature and diameter.

Wenbin LI et al. [2] examined the effect of separation mechanism between ceramic material sleeve & steel shaft on shrink fitting. Process parameters to be employed were shrink fitting ratio, outside diameter D, thickness of shaft, fitted length L and thermal conductivity of the sleeve. They evaluated the effect of each and every parameter on separation time. Process parameters were used in different dimensions, shapes & sizes. Separation time was found to be lesser for comparatively larger outside diameter. Separation time was found to be directly proportional to the shaft thickness. Again, separation time was found to be lesser for a fitted length less than 210 mm. Separation time was also found to be in direct proportionality with heat conductivity of sleeve.

Wenbin LI et al. [3] proceeded further with their analysis of ceramic material conveyer rollers of hot rolling mills. This time they conducted a thermal stress analysis of the ceramic material roller because for ceramic thermal stress is on the higher side hence they applied a close check on it. For thermal stress analysis a finite element analysis was conducted with the help of ANSYS workbench. Process parameters to be employed were shrink fitting ratio, outside diameter D, thickness of shaft, fitted length L and thermal conductivity of the sleeve. Process parameters were used in different dimensions, shapes & sizes. Effect of thermal stresses on all the process parameters was studied.

Nao-Aki NODA et al. [4] studied about the mechanism of separation between sleeve & shaft for the purpose of maintenance of the shaft. Previous study on this topic showed that coming out mechanism between sleeve & shaft was only possible for very low shrink fitting ratio & beyond a specific threshold value it wasn't as consistent as it appears when the value is in desired range. Hence, they shifted their objective from rolling of rollers from shifting the load at an interval of angle θ. For this condition coming out mechanism was studied through finite element analysis on ANSYS workbench. Process parameters to be used were shrink fitting ratio, Young's modulus of elasticity of the shaft & friction coefficient. The results showed that through above cited method coming out process can be seen at larger shrink fitting ratios also. Study of young's modulus & friction coefficient showed that coming out mechanism was possible only at smaller young modulus & smaller friction coefficient only.

S.M. Kamal et al. [5] examined about the factors through which fatigue life of thermally Autofrettaged cylinders through shrink fit may be enhanced. For the study they used an Autofrettaged compound thin cylinder. They calculated the fatigue life of thermally Autofrettaged cylinder with shrink fit for different safe working pressures with the help of paris law. They compared this value with the value calculated for the fatigue life of a no thermally autofrettaged cylinder. The results indicated that with the help of shrink fitting & autofrettaging leads to a better fatigue life.

Tae Jin Kim et al. [6] studied about the analysis of warm shrink fitting process for an assembly. Assembly used for this purpose was shaft and gear assembly. Warm shrink fitting process was used to avoid the noise problem whenever the parts are assembled using press fitting. Process parameters on which the study is based are contact pressure according to the fitting interference between outer diameter of the shaft & inner diameter of the output gear, profile tolerances & fitting temperature. In order to predict the fitting load & contact pressure a close form equation was developed and was duly verified using experimental results & finite element simulation using an analysis tool. In the end thermal structural coupled field analysis & actual loads measured in the field were calculated which agreed with the experimental & simulation results.

Xiaofeng Wang et al. [7] examined the thermal deformation and factors which may affect shrink fitting for an aluminum alloy drill pipe. In shrink-fitting assembly process of aluminum alloy drill pipe with steel joint, the relationship between cooling water velocity, initial heating temperature, and thermal deformation of the steel joint is an important factor to ensure the long-term reliability of the connection and the performance. In this article, the shrink-fitting assembly experiment of aluminum pipe with steel joint was conducted and the accurate experimental data were obtained for temperature field. A relationship diagram among these three factors was established, which is particularly important in predicting the minimum heating temperature of steel joint and the minimum cooling water velocity. Based on the above analysis, a method to select the initial heating temperature and the cooling water velocity was provided and the optimum values of the magnitude of interference, the initial heating temperature, and the cooling water velocity were obtained.

Doo-Sung Lee [8] examined the stress distribution patterns in an elastic layer with a cylindrical cavity. This study was performed on a cylindrical vessel with mixed boundary conditions being prescribed on it. In order to find the solution of this objective, dual integral equations were found with the help of mixed boundary conditions being generated. To find the solutions of these integral equations numerical method was used.

Mojtaba Sharifi et al. [9] studied about the multi layered compound cylinders with shrink fitting and developed some equations for optimum design of these kinds of cylinders using analytical optimization methods. For the study Tresca's yield criterion was employed to minimize the maximum shear stress being generated simultaneously at inner surfaces of all the layers. With the help of it several formulae were derived for obtaining optimum values of layer radii, contact pressures & radial interferences. Then with the help of an analytical method, a technique for shrink fitting was derived in order to obtain the relation between radial interferences & temperature differences for every step of shrink fitting. The results indicated that compound cylinders with a greater number of layers have higher internal pressure bearing capacity at a specified weight. To optimize the effectiveness of these methods three different types of examples were employed. Their study shows that maximum shear stress decreases with the increase of number of layers. This study also revealed that the weight of this compound cylinder decreases with a greater number of layers being employed to develop the cylinder. They concluded that maximum shear stress develops simultaneously at inner surfaces of all the layers. They also stated that using three or more layers can result in lesser weight & higher maximum shear stress in cylinders consistently.

Fabrício Dreher Silveira et al. [10] examined about the possibility of designing and developing a new cold extrusion process for the gear manufacturing because the metal forming process conventionally used for gear manufacturing loses its accuracy when asymmetric gears to be developed. They took the reference of a Brazilian company which produced spur gears using one such cold extrusion process using low carbon steel alloy described as SAE 10B22. For the purpose high speed steel tools were developed.

Guowei Zhang et al. [11] examined about the possibility of introducing a stopper to prevent the coming out phenomena inner plate of sleeve and outer surface of shaft in a heating furnace. For the purpose a finite element simulation was performed the result of which shows that the coming out phenomenon can be prevented. For the prevention to take place, several process parameters were examined which included repeated load, friction coefficient upon the contact & compressive force. These parameters were calculated & compared under large number of loading cycles using simulation process. This study reveals that more than one surfaces of inner plate contact with the outer plate because of repeated load due to shrink fitting. They indicated that a driving force is generated because of which the coming out process takes place and in order to stop this we need to apply an equal and opposite force. They concluded that the contact force and driving force is equal in magnitude with a maximum possible error of 5%.

V Gopalakrishnan et al. [12] studied about the shrink fit philosophy for the rotating components in which room temperature is of primary concern. Their study focused about identifying the loads, safety factor & stress evaluation and interference. Finite element analysis for the same has also been done on ANSYS 17.0 in order to satisfy the results obtained experimentally. They also conducted an experiment to validate their hypothetical results. They concluded that the design procedure they described can be used efficiently for such manufacturing processes.

Christian Mascle et al. [13] Studied about the effects of surface roughness & interference between the mating surfaces on the torque capacity of the shrink fitted assembly. They derived a new method for computing precisely the value of interference. They indicated that roughness profile for the shaft is more regular than that of hub. Torque capacity was measured for three different samples and a statistical analysis of the data obtained was then carried out through analysis of covariance (ANCOVA). The selected ANCOVA calculated the variances and analyzed the whole process.

Haykel Marouani et al. [14] Studied about the finite element simulation of a shrink fit assembly for cyclic radial load. They used the fretting process to model a simple cylinder shape object. They caused a tangential movement of the shrink relative to the hub. For this condition the data has been collected. This study indicates that when the relative motion is localized then the assembly relations are maintained but for some specific condition this local relative motion tends to move to global movement of the object. This study showed that the work done here was in its preliminary stage and a lot of improvement work can be done. No validation was performed in this work. Only a hypothetical indication was made that in some condition there occurs a permanent sliding which may cause the assembly features.

Amol Chougule et al. [15] conducted a finite element simulation of the web type flywheel. They used the flywheel made up of composite material. For the purpose they calculated maximum tensile stresses & bending stresses at the web and rim of flywheel because these two are the sensitive parts of the flywheel assembly. The data calculated by the simulation through ANSYS workbench and are compared with the analytically calculated data. For simulation purpose hexahedral element has been selected because of its advantages over other kinds of elements especially for this application. Flywheel model used for analysis was created using CATIA V5. Their study indicated that deformation caused in conventional steel flywheel is slightly more than composite material flywheel. They concluded that coefficient of fluctuation can be reduced to large extent using composite material web and increasing the weight of the rim so that total weight of flywheel remains the same.

Fahrettin ÖZTÜRK et al. [16] studied about the interference & inter facial pressure for a three disk shrink fit assembly. For the purpose a three disk shrink fit assembly (solid shaft-sleeve-holder) was modeled using finite element simulation in order to examine the effects of the interference or shrinkage allowance on interference or interfacial pressure. Stress values were obtained & stress distribution pattern was plotted along the thickness of the assembly. The maximum stresses were obtained 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. They indicated that this higher stress distribution at the inner surfaces may be reducing by lowering the interference between sleeve and holder. Their study showed that Equal interfacial pressures between disks can be accomplished using different interferences. They concluded that finite element simulation is the only solution for complex geometry and various loading conditions.

R.Vinayagamoorthy et al. [17] studied about the effects of shrink fitting & fitting with key of a radial fan used in several applications across the industry. This study was performed using a finite element simulation in ‘Solidworks’ software. Process parameters to be used were stress, strain, displacement & factor of safety. Their study results in key fitted assembly being more efficient with higher factor of safety. Again, practical performance was also measured for the types and speed, vibration sounds were measured. The study of shrink fit was considered to be failed because of less factor of safety. But practical analysis indicated that shrink fit radial fans may be used for light duty applications for a short span of time. One more advantage that shrink fit has over the key fitted assembly is that it has less noise.

Vinaykumar P S et al. [18] studied about the elastic-plastic analysis of any rotating disk type element in order to forecast burst speed. Initial literature survey showed that any rotating element may fail under thermal or mechanical even before its failure limits. Hence a numerical simulation was done with the help of an elastoplastic finite element analysis of udimet 720, a nickel based super-alloy in order to predict and forecast the burst speed of the disk. They conducted a limit analysis to predict the burst speed. Primary concern here was to know the maximum stress induced in the disk according to maximum normal stress theory. Structural analysis of the disk was conducted at different angular velocities ranging upto 7800 RPM. They concluded that the burst speed is totally a strain dependent phenomenon.

N. Kumar et al. [19] studied about various permutations and combinations of optimizing autofrettage pressure & shrink fit combination in order to minimize the stress generated in multi layered pressure vessel. For the purpose several types of possible sequences of assembly of Autofrettaged and shrink-fit in multilayered vessel have been examined. Study reveals that when we increase the number of layers, effective numbers of sequences also increase and hence our optimization process also provides better results.

Jiao Zhao et al. [20] examined the effect of radial interference on the torque carrying capacity of a shrink fitted camshaft assembly. For the purpose maximum contact strength stress was calculate for a cam shaft assembly and it was seen that for a specific value of radial interference, plastic deformation started and below this value only elastic deformation took place. Hence this value was considered to be the reference value for performance analysis of the camshaft. This reference value was found to be 0.08 mm. Now based on this value a relation was set up between friction coefficient at the contact surface and radial interference using Lame's equation & experimental data. Then a relation between radial interference & torque capacity was developed. The study revealed that the torque capacity curve slope decreases gradually with increasing the radial interference. But the results obtained in elastic range were in good agreement with previous literature.

Zbigniew Siemiątkowski [21] presented the results of investigations on the quality and load ability of the large size crankshafts of the assembled type. Especially in the marine engines, the shrink-fitted joints have to bear large shock loads in order to ensure the safety of the people aboard. Methodologically, however, it is difficult to perform exact load tests on the ready crankshafts, because of their large sizes and eventual destruction after test. The critical force Fcr was measured for each shrink-fitted coupling of the pivot with crank, and the critical value of static torque Mcr was calculated. The test results showed that the relative tightness of 2.02 per mil provided the maximal reliability of the assembled crankshaft with the critical torque Mcrmax = 35 kNm. Increase of tightness up to 2.1 per mil led to the drastic fall of the critical torque down to ca. 26 kNm. The main conclusion was that the critical torque is not higher for relative tightness Ww larger than 2.2%. Thus, in practice, there is no point to make more tight joints, because their reliability does not improve.

Sergei Alexandrov et al. [22] developed a method for elastic/plastic shrink-fit analysis and design is developed. In contrast to many available semi-analytic methods, it is assumed that the outer disc obeys the von Mises yield criterion and its associated flow rule. The inner component of the assembly is purely elastic. The complete solution consists of three principal steps. First, the elastic/plastic solution in the outer disc is outlined. The only output of this solution required for the next step is the circumferential strain at the inner radius. It is shown that this strain can be found without having the strain distribution in the plastic region of the disc. This significantly simplifies the design of shrink fits. Moreover, only two parameters related to the outer disc (Poisson's ratio and the dimensionless inner radius) are involved in numerical part of the elastic/plastic solution in the outer disc. Second, the found circumferential strain at the inner radius is used in conjunction with an analytic solution in the inner component of the assembly to match the two solutions. Any conventional design criterion can be adopted at this stage to determine optimal conditions. The complete solution involves several independent parameters.

M. McMillan et al. [23] studied about the slip at the interface of a shrink fit between a shaft and hub under axial load has been measured by a technique where a small cross hole is drilled through the assembly and a Talysurf profilometer is used to measure the profile of the hole. The finite element study also shows that the extraction load for shrink fit assembly does not increase linearly with the coefficient of friction or the axial length of engagement of the shrink fit, as would be expected from a straightforward analysis.

III. Gaps in Research

Although a lot has been said & done on the topic of shrink fitting & its use in manufacturing of rotating components, there is a lot which can still be done. Some of those have been listed below-

1) Mechanical & thermal analysis of flywheel-shaft assembly on the basis of shrink fitting made up of metals
2) Mechanical & thermal analysis of flywheel-shaft assembly on the basis of shrink fitting made up of composite materials.
3) Hoop stress calculation for flywheel-shaft assembly on the basis of shrink fitting made up of metals and composite materials etc.

IV. Conclusions

1) Some researchers have been successful in bringing to the knowledge some new ceramic materials which may be used for this particular application.
2) Because of shrink fit several losses occurring due to use of other joining methods may be reduced.
3) All the applications applying shrink fit are bound to have a slippage problem after a certain condition.
4) Some researchers have been able to introduce the method for plastic shrink fit analysis.
5) Similar methodology may be employed in case of a flywheel-shaft assembly which will reduce the losses & improve the overall performance of a flywheel shaft assembly.

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