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Thermal Analysis of a Large Shaft in Housing for Shrink Fitting Used in SPM Tools – A FEM approach

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Abstract

In this paper, a brief thermal evaluation of a huge shaft in housing for decrease fitting which is widely used in special reason device gear is carried out. Work is accomplished in 3 phase. Within the first section required interference among the shaft and the bore of the housing to face up to torque is decided. The interference is required to allow the casting and the shaft to rotate together without any slip and usage of bolt clamping. For enabling the decrease-match assembly of the bore and shaft, it's far required to extend the bore to a favored temperature by using software of external warmth supply. The bore is to be heated such that there is enough growth of the bore for a ease operating clearance. This clearance is needed after a length of forty five minutes from start line of cooling. These forty five minutes of time is needed for assembly method of the shaft into the bore. Within the very last segment, the brief thermal analysis of the housing is performed wherein the bore initially at a temperature of a hundred and fifty °C cools right down to a temperature of fifty°C after a term of 45 mins elapsed.

Keywords: *Special Purpose Machine Tools, Shrink Fitting, Housing, Shaft-Bore, FEM*

INTRODUCTION

A shrink-fit is interference in shape completed by using a relative size change after assembly. This is normally performed with the aid of heating or cooling one aspect earlier than meeting and permitting it to return to the ambient temperature after assembly. Shrink-fit assembly is a low value joining method in which warmness is used to produce a completely robust joint between steel additives so one can transmit torque. Those assemblies face up to highly high pressures more efficiently and require less material than single disk. This kind of assembly is characterized by using the amount of interference which provides an extraordinary energy among the 2 elements. The ensuing strain among surfaces mechanically holds the two portions together. Mean while, friction coefficients of two elements are important for introduction of the frictional pressure between the two parts. Cut back-match approach is more regularly used to replace the traditional mechanical fasteners. Common programs of cut back-match meeting are a shaft with equipment, a shaft with steerage knuckle, a shaft with sleeve, device holder assembly, ball bearing, curler bearing, wheels and bands for railway stock, turbine disks, rotors for electric motors roller etc.

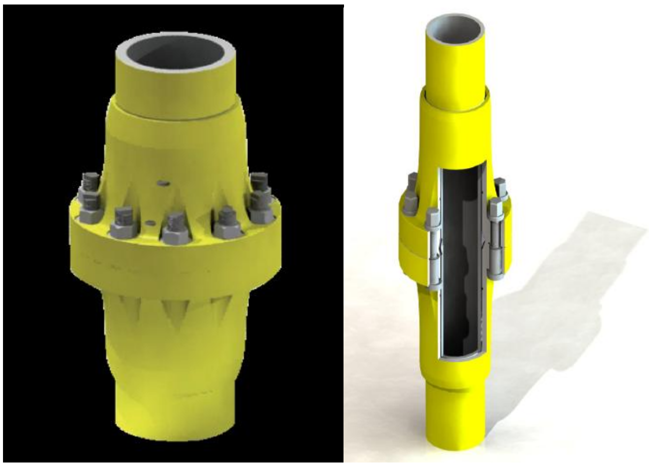

Fig. 1: *Shrink Fit Flange*

Earlier investigation on shrink-fit problem between an eccentric and a centric circular annulus in the elastic domain carried by T Videnic and F Kosel [1] gave analytical solution of a shrink-fit. They assumed that the material constants for both elements are the same and that a plane stress or plane strain state occurs in both annuli. The problem is solved using complex variable functions, where conformal mapping of the centric circular annulus to the eccentric one can be used. Fahrettin Ozturk, Tse-Chien Woo [2] has investigated the three disk shrink fit assembly modeled by finite element method to determine the effects of the interference or shrinkage allowance on interference. 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. D Booker et al.[3] has investigated that the traditional approach to determine the holding torque of a shrink-fit is based on Lame's equation to predict radial pressures at the interface of the components and knowledge of the coefficient of friction and length of contact. This paper examines the validity of this approach and a variant, which takes into account of surface roughness conditions of the interfacing components, by comparing statistical distributions of the holding torque with those found experimentally for a sample of a particular shrink-fit configuration. The probabilistic results of a micromechanical approach are presented which show good comparison with experimental results, indicating that current design formulae are inadequately predicting holding torque. In addition, the phenomenon of increased holding torque with loading cycle number is observed experimentally, and areas where further work needs to be conducted in order to model the situation using frictional and plastic shakedown are outlined.

C E Truman et al.[4] has investigated that the paper treats the problem of a shaft of finite intensity, cut back-outfitted into a cavity and challenge to faraway torsion. The evolution of slip areas along the curved floor of the shaft is discussed and the impact of finite depth is investigated. The give up face of the shaft is tractionunfastened, that's performed by dispensing unique axi symmetric dislocations giving a relative twist displacement over the give up aircraft. This allows the conditions for no-slip alongside the curved floor to be determined explicitly. W. Kim et al.[5] accomplished take a look at on the shrink-suits and internal Clearance variation for Ball Bearing of system tool the usage of FEM. on this approach device pressure in device is extremely vital due to the fact the magnitude of deflection below load determines machining accuracy. The bearing stiffness is major factor that impact device rigidity. consequently, bearing preload is needed to decorate gadget stress and to growth running accuracy. A right amount of negative bearing clearance is proper with the intention to stiffen the support of the spindle. but, irrelevant negative bearing clearance can reason immoderate rolling contact stresses and eventually cause bearing seizure. therefore, right inner clearance need to be decided on that allows you to save you bearing seizure and to improve bearing stiffness. The cause of this observes is to comprehend the inner clearance version and conduct of a bearing that is a deep related with fatigue existence of bearing and performance of spindle through FEM. This paper offers accurate bad internal clearance consistent with temperature all through operation. furthermore, interrelation between thermal expansion and contraction are offered to hold ok contact pressure in spindle gadget. the present work covers design and evaluation of the shaft in a bore. The interference is needed to permit the casting and the shaft to rotate together without any slip.. FEM is carried out to decide the interference that resists the torque, FEM analysis is been carried out to arrive the initial temperature of the bore, so that there is adequate working clearance at the end of time period of 45 min. Transient Thermal Analysis has been carried out for this.

Table 1: *Properties and specification of the material*

Material (CI)	Cast Iron grade 30
Young Modulus (ε)	11,000
Poisson’s Ratio (γ)	0.27
Density of the material (ρ)	7.2 kg/mm^3
Specific Heat of the Material ($C_{p)}$	460 j/kg/°c
Co Efficient of Thermal Expansion (α)	1.1e-5 mm/°c/mm
Convective Heat Transfer (h)	2.8e-5 w/mm^2/°c
Specific Weight (w)	7.8 grams/cc
Film Convective Co-Efficient (h_f)	2.8e-5 w/mm^2/°c
Secant Do-Efficient Isotropic	1.1e-5 mm/°c/mm
Shrinkage	1.19%
Thermal Conductivity (k)	25.2 W/m-K

MODEL DESCRIPTION AND ANALYTICAL CALCULATION

Table 2: *Elements used in the model*

Type Element	Number of Elements
Shell 57	1851
Shell 63	1851
Plane 42	240
Contact 178	12

Thermal Deformation Analysis:

Plate size: 100mm*40mm*4mm thick.

Thermal conductivity = 0.04 ω/deg°C/mm.
Constrained Temperatures: LHS 100°C RHS 30°C (ambient temperature).
The average temperature is 65 deg °C.
The temperature rise over the ambient = 65-30=35°C
Co-efficient of thermal expansion (α) = 1.1E-5 mm/ °C/mm

Thermal expansion (Analytical) = Co-efficient of Thermal Expansion * Rise in temperature * Length
$= \alpha * \Delta T * L$
= 1.1E-5 * (65-30)* 100
= 0.0385 mm.
Thermal Expansion as per ANSYS is 0.0408 mm. There is quite good agreement between Finite element method and Theoreticalprocedures.

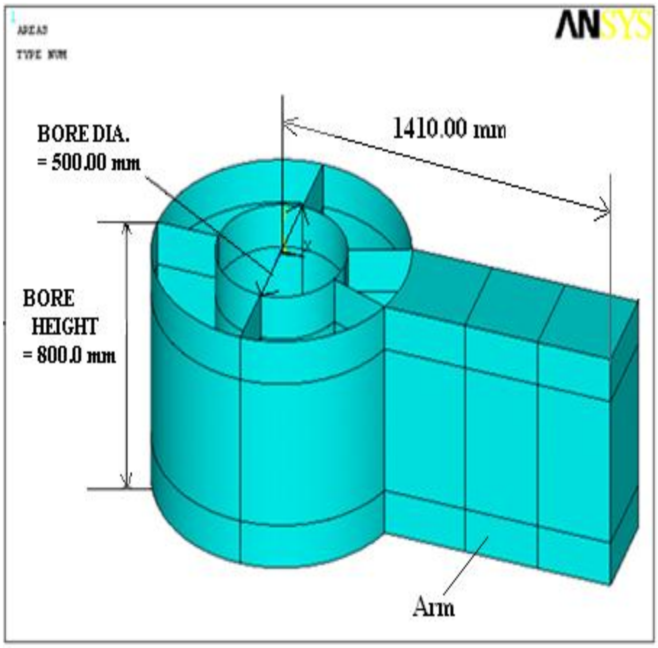

Fig 2: *Dimensional Plot of Bore with Housing*

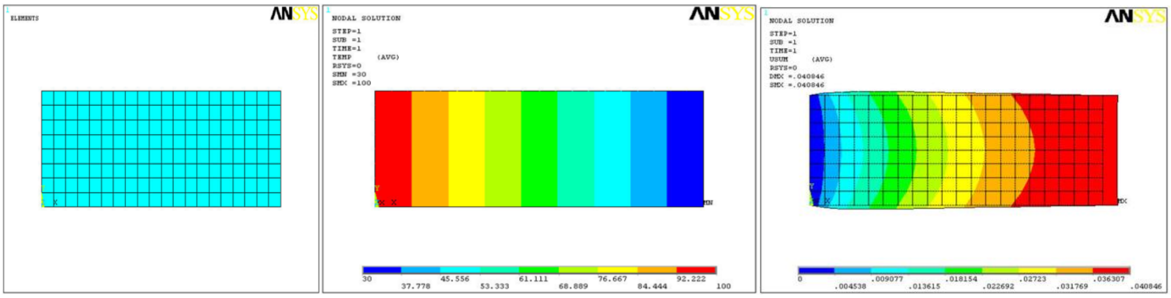

Fig 3: *(a) Solid Element with meshing (b) Solid Element with temperature distribution (c) Thermal deformation of solid element*

Torque Calculation:

Torque to be resisted = Cutting force × Length

$= D \times L$

$= 300 \times 1.410$

$= 423$kg.m (Theoretical)

It is required to find out the extent of interference between shaft and the bore to resist the torque of 423kg.m. The analysis has been carried out by giving different amount of interference in order to find out sufficient resistance to the generated torque during machining. 20 microns interference on radius shows the resisting torque of 515 kg.m is estimated through the Analysis as given below

Normal force (F_N) = Contact pressure × Area of the bore

$= P \times A$

$= (8.2\times10^{-3}) \times \pi \times$ diameter × height

$= (8.2\times10^{-3}) \times 3.14 \times 500 \times 800$

$= (8.2\times10^{-3}) \times 3.14 \times 40 \times 10^{4}$ kg

Tangential force being resisted F_T = Contact field × Normal force

$= \mu \times F_N$

Where Contact field= $\mu=0.2$

$F_T = 0.2 \times 8.2 \times 3.14 \times 400$

$= 2060$ kg.

Resistivity torque =Tangential Force × Bore Radius

$= F_T \times R$

$= 2060 \times 250/1000$

$= 515$kg.m. (ANSYS)

Thus resisting torque is more than the working torque (Theoretical). Hence this interference of 20 microns on radius is sufficient.

THERMAL ANALYSIS

Bore Temperature Determination:

Bore Condition at 50^0C

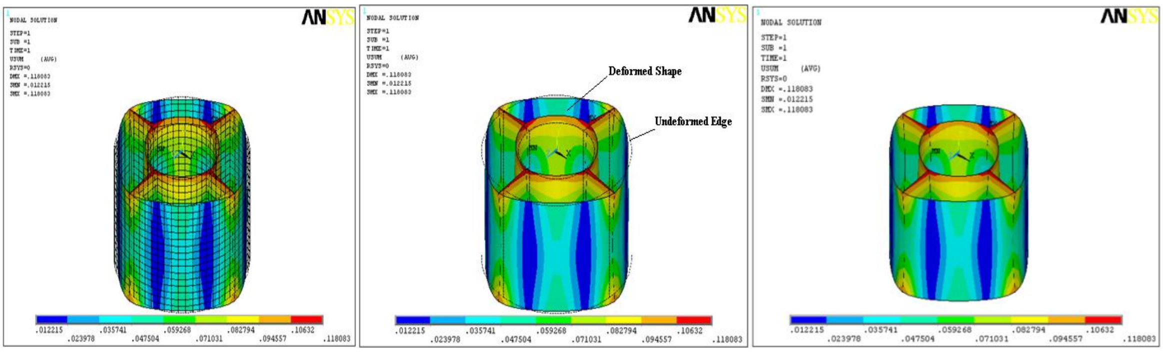

***Fig 4**: 3-D Model of a bore with (a) Undeformed model **(**b)Undeformed Edge (c) Deformed shape*

The temperature of 50°C is applied and observed that the bore will expand on diameter 160 microns. The radial expansion is visible in the model; the red color shows the maximum expansion of bore. The blue color shows the minimum expansion of bore and the yellow color shows the medium expansion of bore. Because of the rib the housing is expanding more along the rib, the expansion is less where there is no rib.

Bore Condition at 75^{0}C

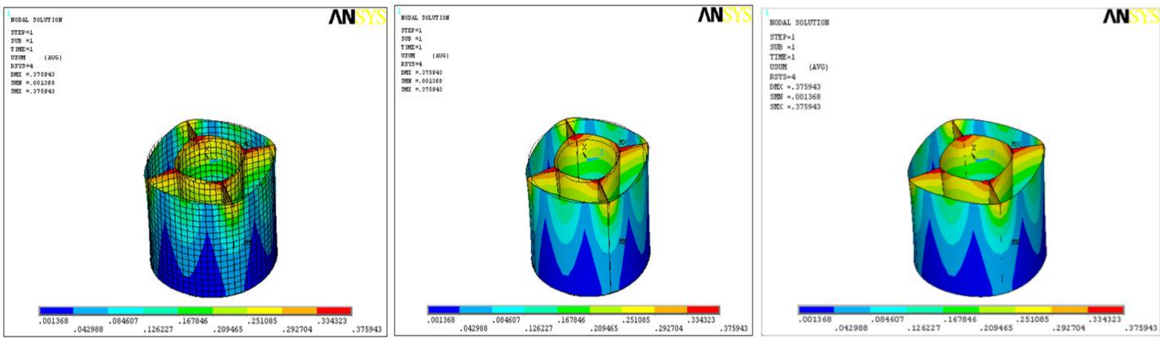

Fig 5: *3-D Model of a bore with (a) Undeformed model* ***(****b)Undeformed Edge (c) Deformed shape*

In this case the temperature of 75°C is applied to the 3D model of bore with properties similar to the previous case. Here that the bore will expand on diameter 524 microns. In this case the deformation is higher compared to the previous case.

Bore Condition at 100^{0}C

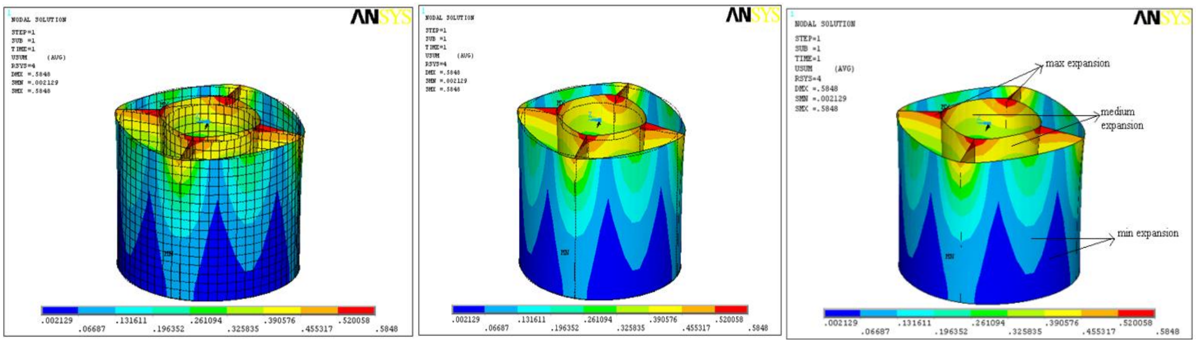

Fig 6: *3-D Model of a bore with (a) Undeformed model* ***(****b)Undeformed Edge (c) Deformed shape*

In this case also the temperature of 100°C is applied to the 3D model of bore with properties similar to the previous cases. In this it is observed that the bore will expand to a diameter 818 microns. Here the deformation is very much higher compared to the both above cases.

The Thermal Analysis shows that a 50°C temperature at the bore gives adequate working clearance. So this temperature i.e.50°C is sufficient for assembling of

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shaft and bore. For shrink-fitting the assembly the assembler needs some time to assemble the shat and bore. Here 45 minutes is taken as assembling time. From this analysis the temperature required for the bore at the end of 45 min is 50°C. Therefore it's important to find the initial temperature required on the bore so that at the end of 45 min it should have a temperature of 50°C., which needs to be computed.

Transient Thermal Analysis at Different Time Interval:

Transient Thermal Analysis at Different Time Interval with Initial T100°C

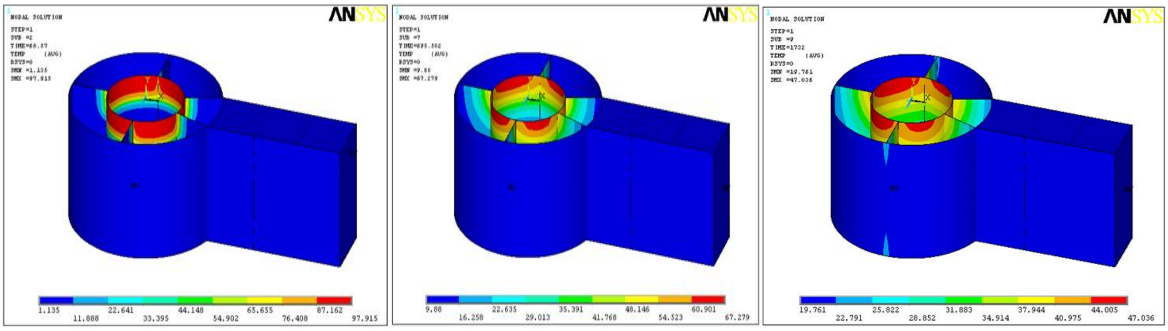

Fig 7: *Transient Thermal Analysis of bore temperature at the end of (a) 1 min (b) 15 min (c) 30 min giving initial temperature 100°C.*

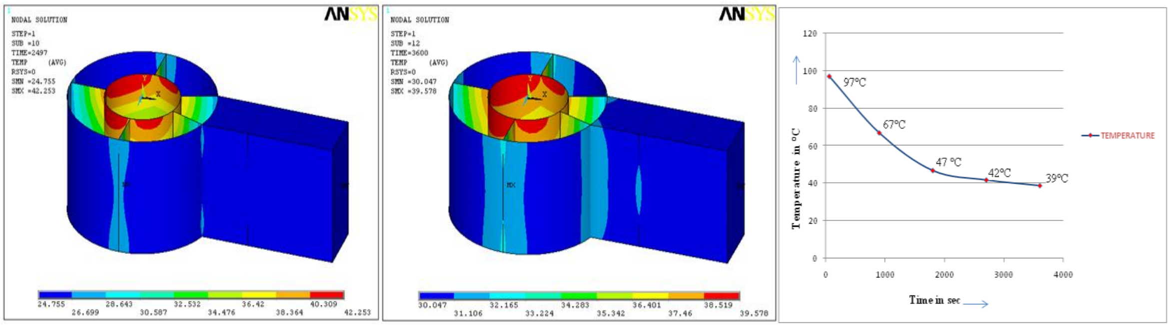

Fig 8: *Transient Thermal Analysis of bore temperature at the end of (a) 45 min (b) 60 min giving initial temperature 100°C (c) Temperature values of graph at different timings*

Applying the boundary conditions and if the designer gives 100°C initial temperature in transient thermal analysis, after 1 min, we get 97°C temperature of the bore, similarly after 15 min time interval, the bore have a temperature 67°C, after 30 min time interval the bore will have 47°C temperature, for 45 min time interval the bore will have 42°C temperature, for 60 min time interval, the bore will have 39°C temperature. Above graph shows the temperature values of graph at different timings with initial T100°C, as the time increases the temperature will decreases in transient thermal analysis. When initial temperature is 100°C the temperature after 45 min is 42°C. Hence this temperature is less than the desired value of 50°C, so this initial temperature of 100^0 C is discarded and trials for 150°C is carried out.

Transient Thermal Analysis at Different Time Interval with Initial T150°C

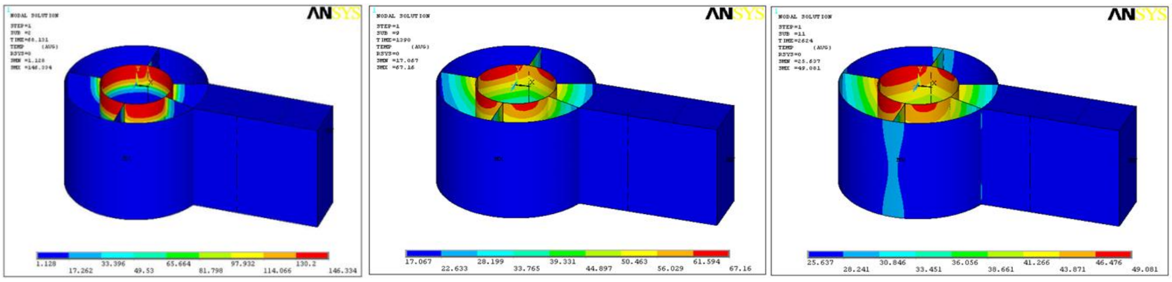

Fig 9: *Transient Thermal Analysis of bore temperature at the end of (a) 1 min (b) 15 min (c) 25 min giving initial temperature 150°C*

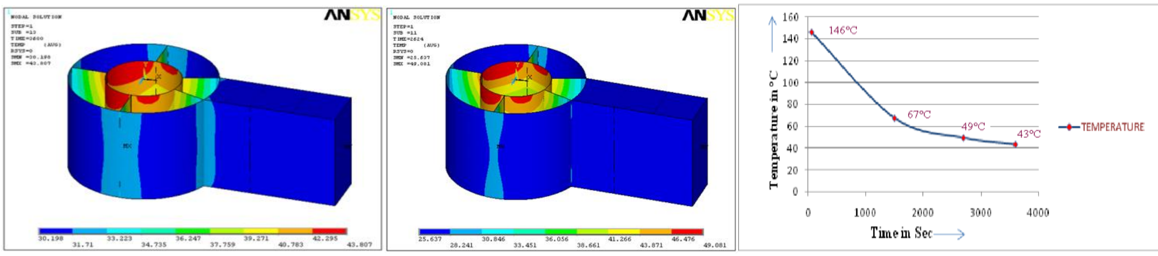

Fig 10: *Transient Thermal Analysis of bore temperature at the end of (a) 45 min (b) 60 min giving initial temperature 150°C (c) Temperature values of graph at different timings*

The data similar to the above case are applied and thermal deformation has been computed.

From the graph it is observed that as the time increases the temperature will decreases. When the initial temperature 150°C the temperature after 45 min is 50°C. Hence this temperature is sufficient to shrink-fit the shaft into the bore of housing. The required interference between shaft and bore of the housing to resist a torque is obtained from this temperature.

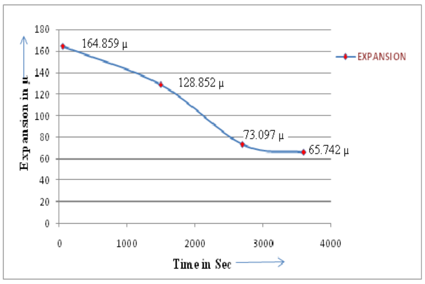

Fig 11: *Deformation values of graph at different timings with initial T150°C*

Fig.11 shows the Deformation values of graph at different timings with initial T150°C as the time increases the expansion will decreases. Here 45 min is taken as assembling time. From this analysis the temperature required for the bore at the end of 45 min is 50°C at time interval of 45 min, the expansion of bore cools to 73 microns

Comparative Study:

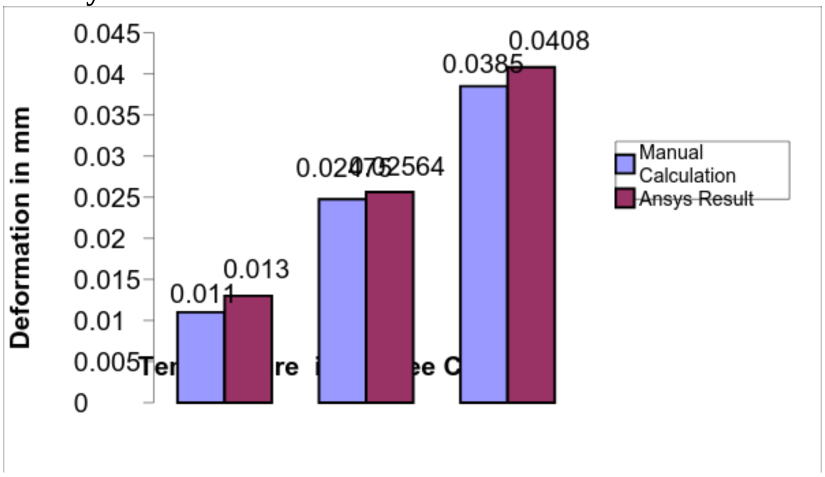

Fig 12: *Bar chart of Ansys results is comparison with the manual calculations*

Fig.12 shows the bar chart comparison of FEM results with the theoretical calculations. There is no much difference than finite element method and theoretical procedures, there is quite good agreement between finite element method and theoretical procedures.FEM is carried out to decide the interference that resists the torque, FEM analysis is been carried out to arrive the initial temperature at the bore, so that there is adequate working clearance at the end of time period of 45 min.

CONCLUSIONS

A finite element analysis of the assembling process of a shaft in bore is presented. A shaft of 500.02 mm diameter is shrink fitted in to the bore of housing.The analysis is carried out in three stages. Initially the required interference between shaft and the bore of the housing to resist a torque 515 kg.m is computed to be 20 microns on radius. In the second phase the required bore temperature to get a working clearance of 20 microns on radius is computed to be 50°C. This temperature is to be maintained after 45 minutes of heating cycle. This 45 minutes time is required for assembly process of the shaft into the bore. In the last phase Transient thermal analysis of the housing showed that the initial temperature of the bore is 150°C. The analysis moved that until an initial temperature of 150°C, the temperature after
minutes of cooling is at least 50°C.The entire analysis has been carried out by using finite element approach. The predicted finite element method results have been validated using analytical calculations whole showed good agreements.

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