INVESTIGATION OF STRESSES IN FLAT BELT PULLEY BY FEM AND PHOTOELASTICITY

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Abstract

There are many causes of pulley failure. Among them the maximum bending stress induced in the arm near the hub end is one of the causes of pulley failure. Hence in this work evaluation of stresses in the arms near the hub of pulley is studied using finite element method and Photoelasticity . Also the effect of variation of number of arms on stresses near the hub is studied. The results of finite element method are verified experimentally using Photoelasticity and analytical calculations. The model of Four, Six and Eight arm pulley are developed for FE and Photoelastic analysis. As the arms are subjected to different loads in the load zone, maximum Von Mises stress is determined at various angular positions of arms for each pulley. The good agreement is observed between the results obtained analytically, by FEM and by Photoelasticity.

Keywords: Pulley,Arm,FEM,Photoelasticity

1. Introduction

As the name implies, stress analysis is the complete and comprehensive study of stress distribution of specimen under study. The most important task before design engineer is to maintain the working stresses within predetermined specific limits, in order to avoid the failure of a member. The design has to be economical with adequate mass and inertia. To improve the product quality, it is necessary to determine the stresses in various components. It is also necessary to know the stress distribution in order to predict the failure of component. This puts the design engineer into indispensable need for stress analysis.

One of the main causes of pulley failure is the large bending stress developed in the arm near the hub of the pulley arm. Hence it is necessary to evaluate the stresses in the arm of pulley. In the present work the stresses in the arms near the hub end are evaluated by varying the number of arms and also for various angular positions of arms. The finite element analysis is carried out using ANSYS. The results of the finite element analysis are verified experimentally using Photoelasticity and analytical calculation.

2. Geometrical Dimensions of Pulley and Loading on Arms

It is intended to use the same geometric model of pulley under identical loading condition for FE analysis, experimental analysis and analytical calculations for comparison of stress. The major dimensions of pulley considered for present analysis are as follows.

Diameter of pulley	D = 150 mm
Diameter of hub	d = 40 mm
Number of arm	n = 4,6 & 8
Thickness of arms	h = 6 mm
Rim thickness	R_{th} = 15 mm

To use the identical loading conditions for FE, Photoelastic and analytical analysis, it is felt necessary to determine the coefficient of friction (μ) between belt material and pulley material. The frictional surfaces considered for determination of coefficient of friction are leather and epoxy resins, which are considered for Photoelastic analysis. So an experimentation using an inclined plane setup is carried out for the same and the coefficient of friction of 0.129 is obtained. For Photoelastic analysis, the maximum torque of 0.816 N-m is considered so that no belt slippage should occur under load during experimentation. Using this loading condition belt tensions in tight and slack side are calculated as 33.07 N & 22.1 N respectively. The angle of lap of 180 degrees is considered for analysis. This loading condition is also considered for FE, Photoelastic and analytical investigation.

3. Finite Element Analysis of Pulley Arms

For finite element analysis, the FE models of 4,6 & 8 arm pulleys are considered. A PLANE 82 element is considered for FE analysis. The model of Six arm pulley is shown in fig. 1 as an illustration. The inner portion of the hub is constrained and load is applied on the periphery of the rim as per belt tensions in tight and slack side. The von- mises stress contour for six arm pulley is shown in fig 2 as an illustration.

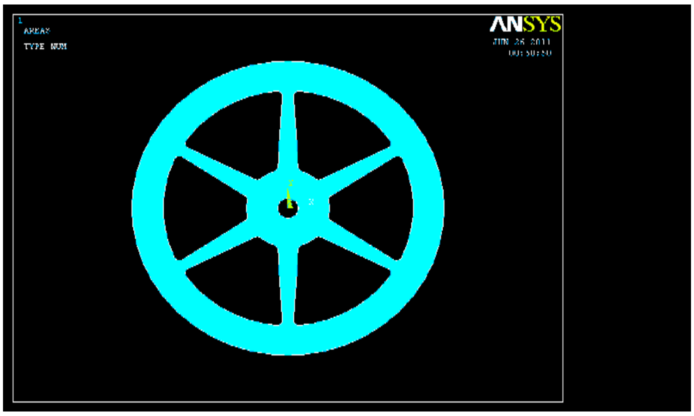

Fig.1 - Model of Six Arm Pulley

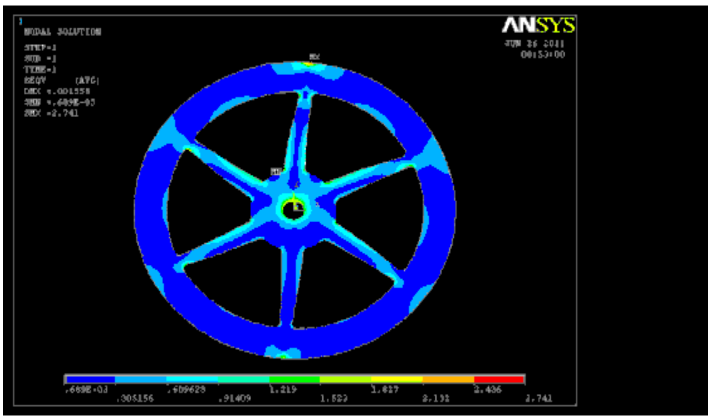

Fig.2 - Von Mises Stress Contour for Six Arm Pulley

4. FE Analysis For Various Angular Positions of Arms

This analysis is carried out for various angular positions of the pulley in the load zone as shown in fig.3. Maximum von mises stress induced in the arm for various arm positions are determined for 4, 6 & 8 arm pulley. In this analysis the stresses are evaluated in the step of 10 degrees rotation for 4 & 6 arm pulley and in the step of 15 degrees rotation for 8 arm pulley. The von- mises stress in arms for different angular positions are given in Table 1,2 & 3 for 4, 6 & 8 arm pulleys and their graphical representation is shown in Fig 4 , 5 & 6 for 4 , 6 & 8 arm pulley respectively.

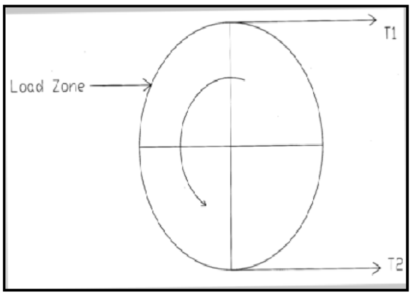

Fig. 3 - Load Zone

Table 1: Von Misses Stresses in Four Arm Pulley

Arm Position	**Von Misses stresses in N/mm^2**			
Degrees	**Arm1**	**Arm2**	**Arm3**	**Arm4**
10	3.01	0.57	0.79	2.1
20	2.41	0.71	1.03	3.01
30	2	0.61	1.4	3.17
40	1.85	0.6	1.49	3.01
50	1.69	0.62	1.45	3.1
60	1.5	0.56	1.81	3.19
70	1.32	0.63	1.87	3.39
80	1.14	0.76	2.4	3.41
90	1.02	0.67	2.47	3.1

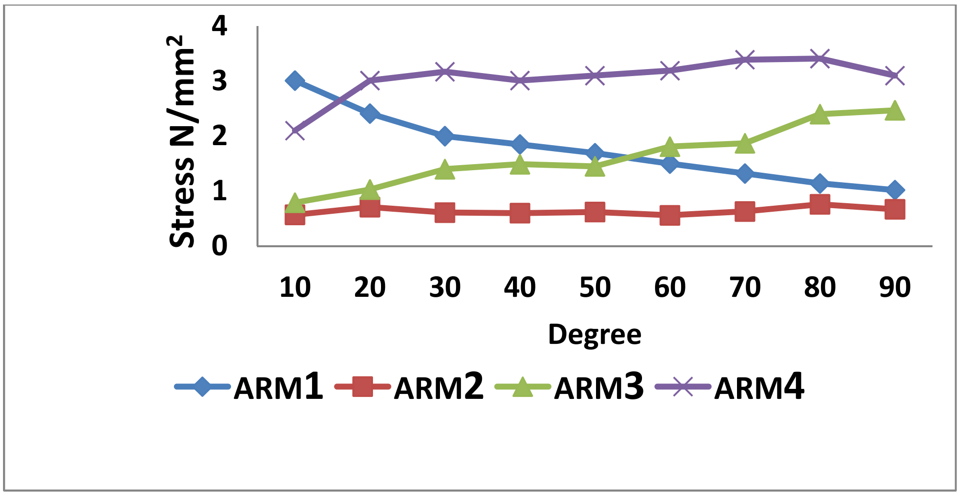

Fig.4 - Variation of Von Misses Stresses in Four Arm Pulley

Table2 - Von Mises Stresses in Six Arm Pulley

Arm Position	Von Mises Stresses in N/mm^2					
Degrees	Arm1	Arm2	Arm3	Arm4	Arm5	Arm6
10	1.4	0.89	0.73	1.02	1.63	2.02
20	1.52	0.67	0.59	0.83	1.6	1.96
30	1.31	0.57	0.51	0.94	1.82	1.92
40	1.07	0.69	0.69	1.24	1.71	1.86
50	0.88	0.66	0.79	1.06	1.81	1.82
60	0.78	0.66	0.87	1.31	1.86	1.54

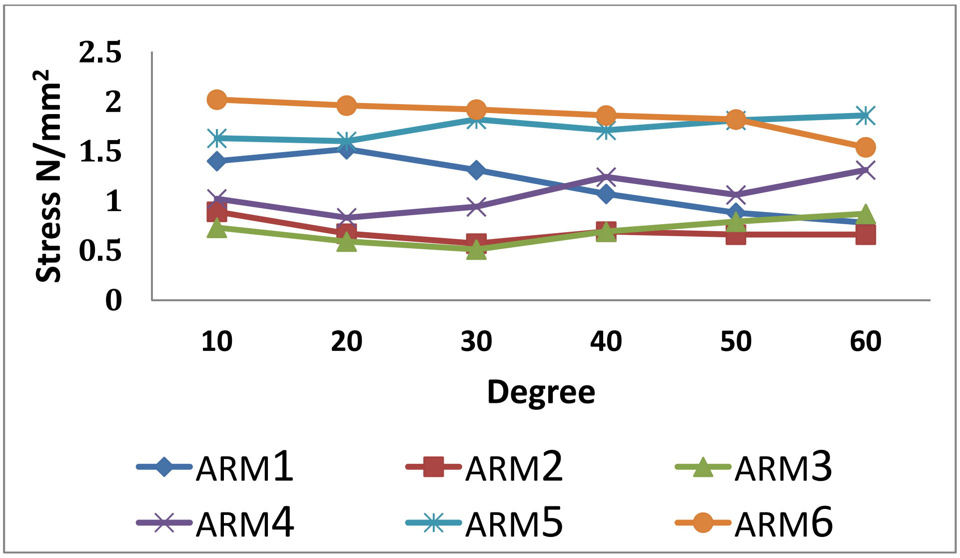

Fig. 5 - Variation of Von Mises Stresses in Six Arm Pulley

Table3 - Stresses in Eight Arm Pulley

Arm Position	Von Misses Stresses in N/mm^2							
Degrees	Arm1	Arm2	Arm3	Arm4	Arm5	Arm6	Arm7	Arm8
15	0.98	0.42	0.52	0.42	0.82	1.09	1.38	0.86
30	0.57	0.55	0.47	0.62	1.12	1.3	1.39	1.46
45	0.59	0.41	0.65	0.98	1.2	1.34	1.14	0.75

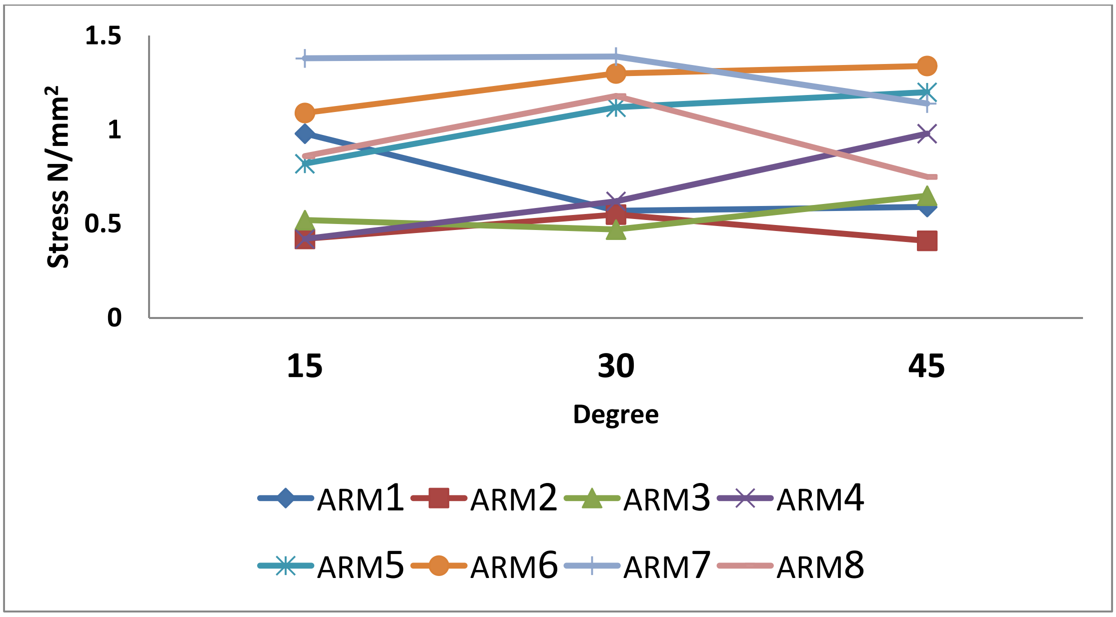

Fig. 6 - Variation of Von Misses Stresses in Eight Arm Pulley

5. Experimental Stress Analysis using Photoelsticity and Analytical Estimation of Stresses

For Photoelastic stress analysis of pulley with 4, 6, 8 arms, the Photoelastic models are prepared from photoelastic material having the material fringe value of 10.902 N/mm- fringe. The experimental setup is shown in fig 7. The torque of 0.816 N-m is applied by a weight of 320 gms at the end of lever arm. The isochromatic fringe pattern seen in circular polariscope is shown in fig 8 for six arm pulley as an illustration.

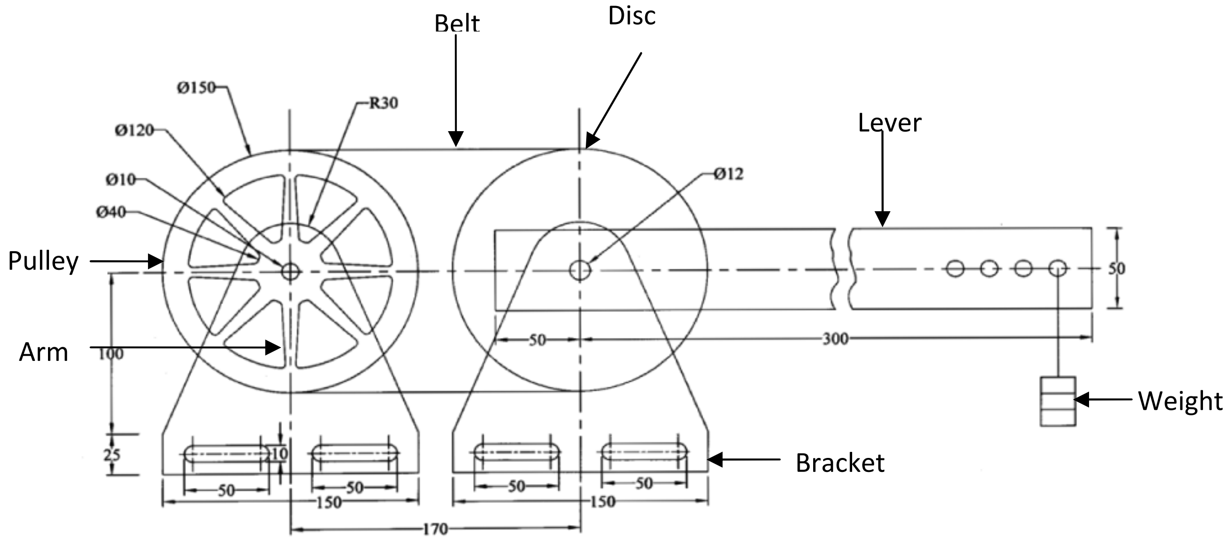

Fig. 7 Loading Fixture for Photoelastic Analysis of Six Arm Pulley

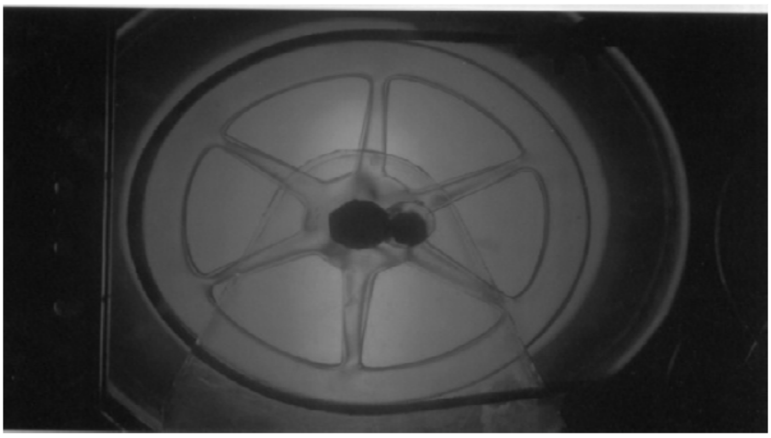

Fig 8 – Isochromatic Fringe Pattern in Pulley Arms

Table 4 – Stresses Evaluated in Arms Near the Hub by Photoelasticity

Sr. No.	Number of Arms	Arm No.	Four Arm N/mm^2	Six Arm N/mm^2	Eight Arm N/mm^2
1	4,6 & 8	1	3.28	2.14	1.6
2		2	3.13	2.06	1.21
3		3	2.7	2.11	1.08
4		4	3.19	2.03	0.97
5	6 & 8	5	-	2.04	1.09
6		6	-	2.12	1.14
7	8	7	-	-	1.19
8		8	-	-	1.3

The analytical equation for bending stress in arms of pulley by considering that half of total number of arms share the load is given in equation no. 1

$$\sigma = \frac{(T_1 - T_2)(D - d)}{N \times Z} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where T_1 & T_2 are belt tensions in tight and slack side respectively. D & d are pulley diameter & hub diameter respectively and N & Z are number of arms and section modulus of arm near the hub. The analytical value of stresses are calculated as 3.01N/mm^2, 2.01 N/mm^2 & 1.51 N/mm^2 for 4, 6 & 8 arm pulley respectively.

6. Discussion and Conclusion

Though the detailed results are presented earlier, here an attempt is made to compare the results obtained analytically, by FEM and experimentation. For comparison of stresses Von Mises stress is considered. This comparison is shown in table 5 and also shown in fig 9.

Table 5 - Comparison of Stresses

Sr No.	No. of Arm	Maximum Stress calculated analytically N/mm^2	Maximum Stresses By FEM N/mm^2	Maximum stress with analysis Experimental Analysis N/mm^2
1	4	3.01	3.41	3.28
2	6	2.01	2.02	2.14
3	8	1.51	1.46	1.6

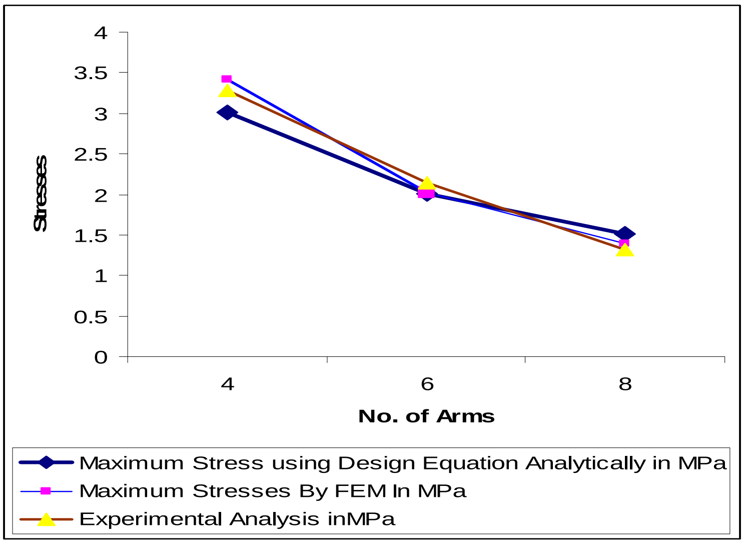

Fig. 9 - Variation of Maximum Bending

From table 5 and fig. 9 it is seen that the good agreement is obtained between analytical, FEM and experimental results for Four, Six and Eight arm pulley. It is seen that maximum error is in between 8% to 9% w.r.t. experimental results, which is acceptable.

It is also observed that, the maximum stress present in the arm of pulley varies for various angular positions of arm. It is seen that maximum Von Mises stress for Four arm pulley exist for 80^0 angular position. While for Six Arm Pulley the maximum Von Mises stresses occurred for 10^0 angular positions. Similarly for Eight Arm Pulley maximum Von Mises stress is observed at the angular position of 30^0. The maximum stress can further reduced by increasing the fillet radius near the hub and near the rim.

It is seen that the existing analytical equation for determining the maximum stresses in the arms by assuming that half of the arm share the load gives very close results with FEM and experimental analysis. Thus it can be concluded that the analytical equation with the assumption of half of the arms share the load seems to be acceptable.

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