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Evaluation Of Mesh Stiffness And Torsional Rigidity In Spur Gear

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Abstract

This work aims to investigate the main parameters affecting noise and vibration encountered in spur gears. They are torsional mesh stiffness and transmission error through a complete cycl . FEM was used for the theoretical aspect of the work .

It analyzed and formulated all the necessary aspects dealing with mesh stiffness and transmission errors , for single and double pairs of spur teeth in mesh .

The experimental part involved , manufacturing of actual spur gears embodied in experimental rig to investigate the parameters mentioned above .The experimental results were compared with those obtained from the theoretical formulations .

It is shown that the torsional stiffness increases in the case of double pairs and decreases in the case of single pair , Also one the main conclusions revealed that the transmission error varied sinsoidally from double pair mesh to single pair mesh as to the noise effect .

الخلاصة

يهدف البحث الحالي إلى التعرف على العناصر الرئيسة والتي قد تكون سبب رئيسي في ظهور الضوضاء والاهتزازات عند دوران التروس وهي جساءة تعشيق اللي وخطأ النقل الاستاتيكي خلال دورة تعشيق كاملة.

تم توظيف طريقة العناصر المحددة FEM في الجزء النظري من خلال التحليل لزوج مفرد من الاسنان وزوجين في حالة تعشيق.

أما الجزء العملي فقد تم تصنيع زوج من التروس المستقيمة لقياس العناصر أعلاه ومن ثم مقارنة النتائج العملية مع النتائج النظرية فكانت جساءة تعشيق اللي تزداد في حالة زوجين من الاسنان وتقل في حالة زوج واحد من الاسنان كذلك يتغير خطأ النقل على شكل موجه جيبية خلال زوجين من الاسنان إلى زوج

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مفرد من الاسنان هذا التغير المفاجئ سبب رئيسي في توليد الضوضاء والاهتزازات.

Keywords

$K_{p,g}^{B}$	**Stiffness of pinion and gear at point B**	**N.m/rad**
$T_{p,g}^{B}$	**Moment of pinion and gear at point B**	**N.m**
$Q_{p,g}^{B}$	**Angle of pinion and gear at point B**	**Rad.**
$R_{p,g}^{B}$	**Readies of pinion and gear at point B**	**M**
$F_{p,g}^{B}$	**Force applied at pinion and gear at point B**	**N**
$B_{p,g}^{B}$	**Displacement of pair tooth at pinion B to pinion and gear respectively**	**mm**
$H_{p,g}^{B}$	**Contact deformation for two pair of teeth at point B**	**mm**

1- INTRODUCTION

Gears are one of the most critical components in industrial rotating machinery. In recent years, many different procedures have been developed to model the behaviour of gears in mesh.Examples of this can be seen in references(Kahraman and Singh 1991; Kuang and Yang 1992; Daniewicz et al. 1994). The torsional mesh stiffness is defined as the ratio between the torsional load and the angular rotation of the gears body. The torsional mesh stiffness varies throughout the meshing position. The development of torsional mesh stiffness model of gears in mesh can be used to determine the transmission error throughout the mesh cycle.

When the pinion rotates to the pitch point P the single tooth torsional mesh stiffness of both gears are equal because both of the gears are assumed to be identical spur gears with ratio 1:1

The single tooth torsional mesh stiffness of the pinion and gear at point B (fig.1) given respectively by :

$$K_p^B = \frac{T_p^B}{\theta_p^B} \quad \text{pinion} \qquad (1)$$

$$K_g^B = \frac{T_g^B}{\theta_g^B} \quad \text{gear} \qquad (2)$$

The meshing stiffness (K) for single pair and double pair in mesh can be added using the rules of series and parallal combinations as shown in figures (1) and (2) where P and g denote pinion and gear respectively.

2-ANALYTICAL MODEL

Gear Body Rotation Compatibility

Evaluating load share between meshing teeth gears is a complex when more than one-tooth pair are simultaneously in contact and an iterative numerical solution must be used. When the gears are put into mesh as shown in fig.(2), the line tangent to both base circle is defined as the line of action for involute gears . In one complete tooth mesh cycle, the contact stars at point A fig.(3a), between the tip of the output gear and the root of the input gear (pinion), a second tooth pair is already \in contact at point D . As the gear rotates the point of contact will move along the line of action APE . When the first tooth pair reaches point B, the second tooth pair disengages at point E leaving only the first tooth pair in the single contact zone. When this first tooth pair rotates to point D the next tooth pair rotates to point D, the next tooth pair begins engagement at point A which starts another mesh cycle. The torque vectors are defined by following:

$$T_p^B = R_p^B x F_p^B, \qquad (1)$$

$$T_g^B = R_g^B x F_g^B, \qquad (2)$$

$$T_{tot,p}^{A,D} = T_p^A + T_p^D, = (R_p^A x F_p^A) + (R_p^D x F_p^D), \qquad (3)$$

$$T_{tot,g}^{A,D} = T_g^A + T_g^D, = (R_g^A x F_g^A) + (R_g^D x F_g^D), \qquad (4)$$

$$\theta_p^B = \frac{B_p^B + H_p^B}{R_p^B} \qquad (5)$$

$$\theta_g^B = \frac{B_g^B + H_g^B}{R_g^B} \qquad (6)$$

3- Finite Element Model Of Gear in Mesh

A finite element model of two gears in mesh is generated using the facility of contact analysis provided by FEM program ANSYS (5.4). The whole body of gears in mesh was modeled where as most of the previously published works were directed toward a specific areas of gear body. The model employed the quadaratic 2D plain strain element and the 2D point–surface contact element. The contact element was generated as a symmetric contact.

4-EXPERIMENTAL WORK

The main objectives of the experimental work were investigate the torsional mesh stiffness and transmission error of a single pair of teeth in contact.

The work is done on the test rig shown in fig (7). The rig consists of two identical spur gears in mesh contained in a gear box of hard walls.

The test procedure is summarized as follows :-

1. Holding one of the gear fixed and applying an external torque using hanging static load (38.3 N. m) on the external pulley.
2. Fixing of strain gauges on the loaded tooth at the point of contact and recording the value of strain using the strain meter.
3. Increasing the applied torque in different values and recording the values of strain.
4. Changing the point of contact and repeating the step (2) and (3).

3.2- Apparatus and Procedures

The specifications of the gears are shown in table (1). One of shafts carrying the gears is has an external pulley of (120 mm) diameter fitted for the purpose of static torque application. The other shaft (second gear) is held stationary by a steel key. Appendix (A) see the test procedure.

Gear type	Involutes, full depth teeth
Material	Steel
Modulus of elasticity	$69x10^9$ N/m^2
Face width	0.015 m
Module, m	8 mm
Pressure angle	20 deg
Theoretical angle of meshing cycle	24.912 deg
Addendum	1module
Dedendum	1.25module
Poisson's ratio	0.3
Number of teeth	10,20

5-Result And Discussions

1- Stress Analysis

From figure Shown (9-10) shear stress analysis (sxy) and Vonmisses stress where the stress centroed in the root and the path of contact , this stress decreases in the area of center that reason go to involutes profile of teeth from the tip to center of gear(hub). Figures (11 and 12) shows stress analysis in X and Y direction for single tooth in contact, show that the stress be elliptical and increased gradually, those stress causes fatigue and pitting which is the main reason caused noise and vibration.

2- Torsional Mesh Stiffness

From figure shown (13) the torsional mesh stiffness of the gear mesh of the input at practical position was obtained by calculating the gradient from corresponding torque versus angular displacement relationship. By changing the meshing position, tensional mesh stiffness of the gear during the entire meshing cycle was obtained. All together 58 meshing position were investigated each mesh position differing by 0.5 degrees. The meshing measurement started at reference 0 degree and finished at 28.5 degrees. However, one complete meshing cycle is 24.91 degrees. The total length of double contact zone (distance AB+DE) is 20 mm (18.5) degrees and the length of single contact zone (distance BD) is 7.2 mm, (6.3 degrees). The graph of tensional mesh stiffness versus meshing position indicates that the changes according to the meshing position of the gears. When the meshing position was subjected to double teeth pair in contact, the torsional mesh stiffness increased and decreased as the meshing approached one tooth pair in contact. This result apper closed to study of (Siricha et al. 1998, Tradegard et al 1998).

3-Transmission Error

The static transmission error of the gear in mesh is term used to describe the difference between the theoretical and actual angular position between a pinion and a gear. Transmission error is considered to be one of the main important causes of gear noise and vibration. Figures (12 and 15) show the relationship between input load (38.1, 76.2, 114.3, 152.4 Nm) and one tooth mesh cycle.

As expected, the amplitude of the transmission error is directly related to the magnitude of applied torque, which is similar to other published work on the static transmission error (Munro and Yildirim 1994, Velex et al 1995) .

The transmission error of each half of the cycle mesh is not reflected at the pitch point but varies throughout the enter mesh cycle. For the second half of the double pair contact zone, the transmission error is slightly higher than the first half of the double pair contact zone. This is because the contact point moves closer to its tip. Transmission error change take place at the entry and exit of mesh, and at the transition point between two teeth to one tooth in contact, and vice-versa. These sudden changes are higher, so it should generate more vibration and noise.

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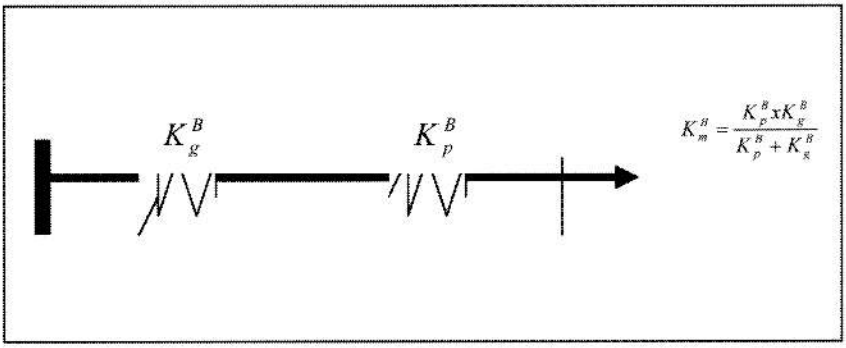

Fig (1) Single tooth in series contact

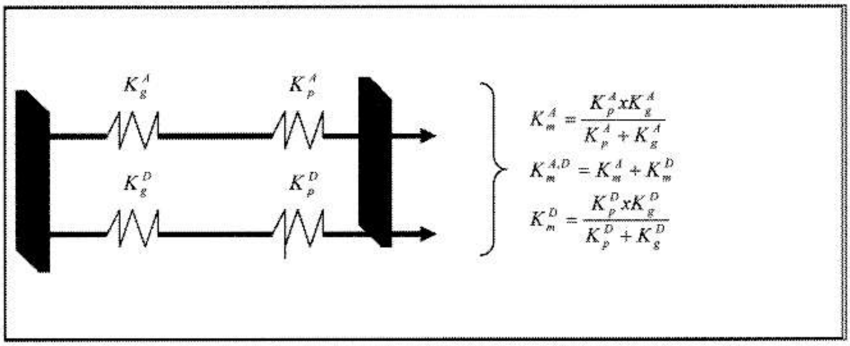

Fig (2) Teeth In Parallel Contact

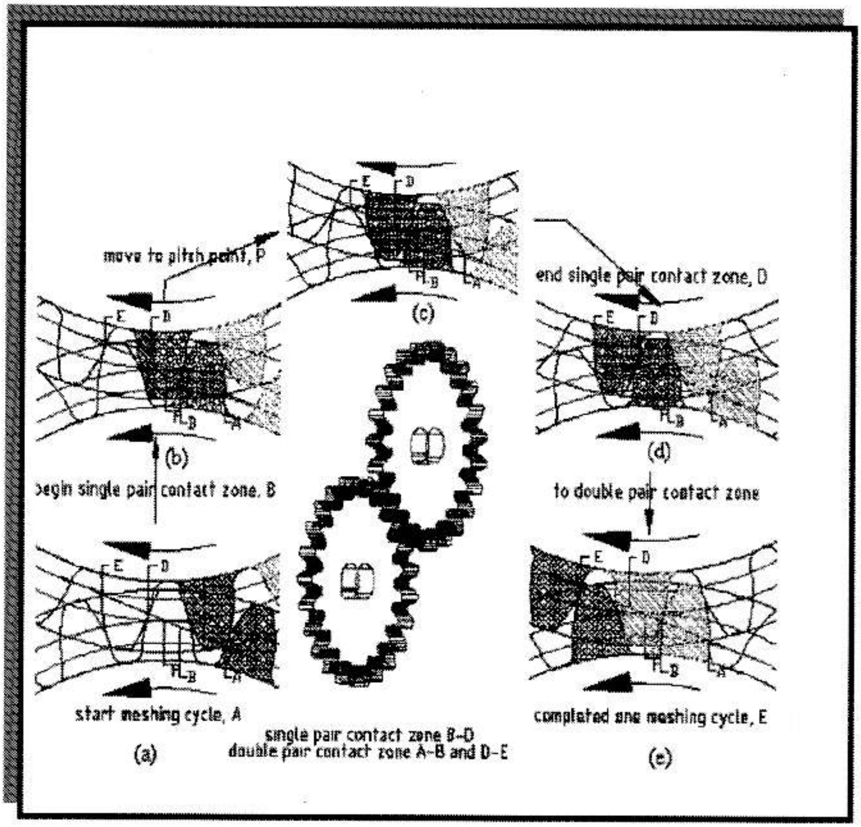

Fig. (3) One complete tooth meshing cycle

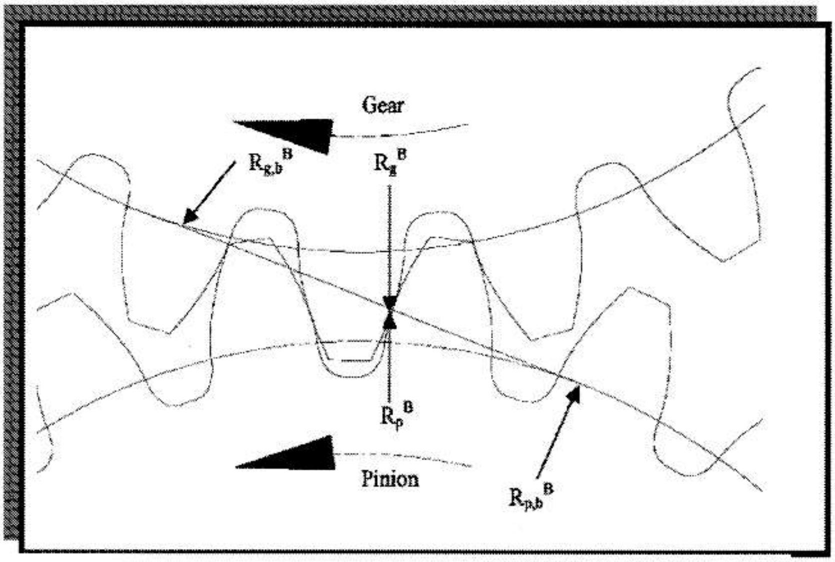

Fig (4) Single pair contact zone at point B

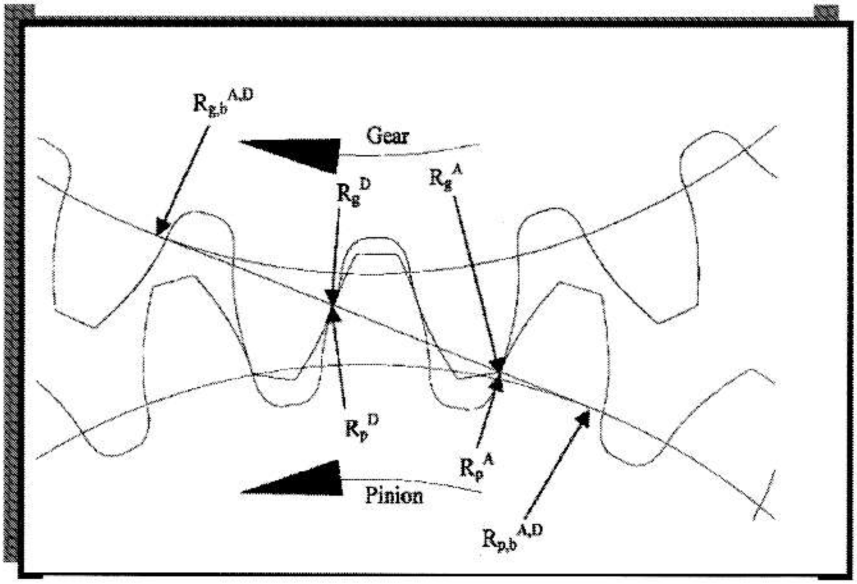

Fig (5) Double pair contact zone at point A and D

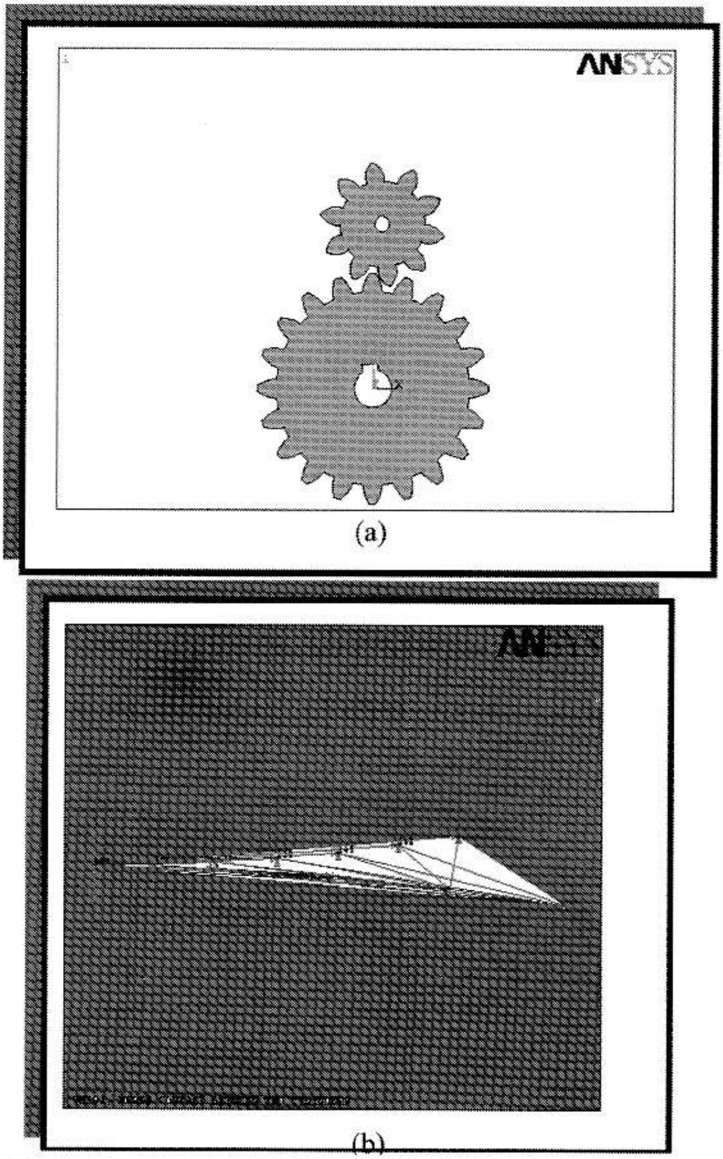

Fig (6) (a) Tow gear in mesh (b) point –to-Surface element

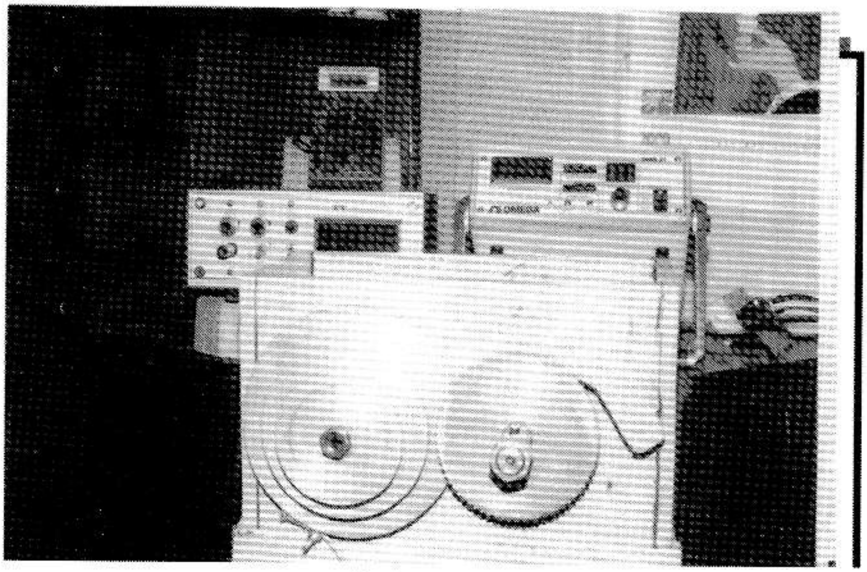

Fig (7) Test rig

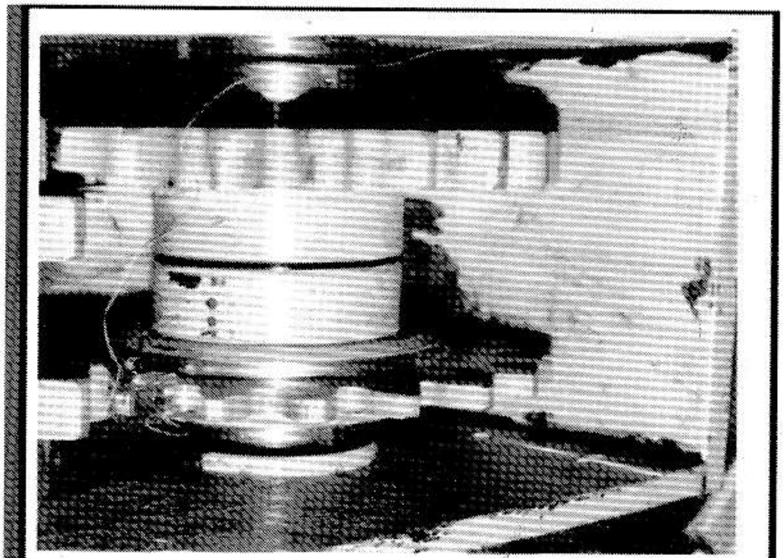

Fig (8) the strain gauge on tooth at contact

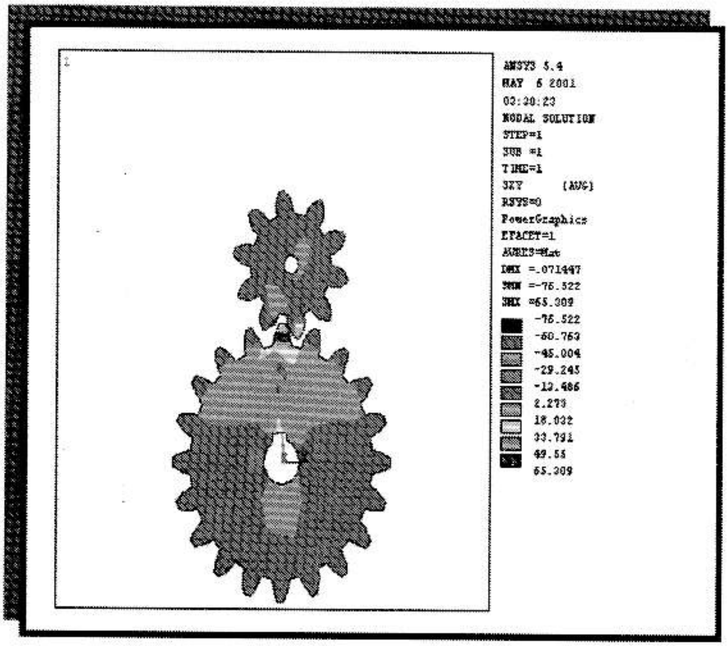

Fig (9) Shear Stress Analysis

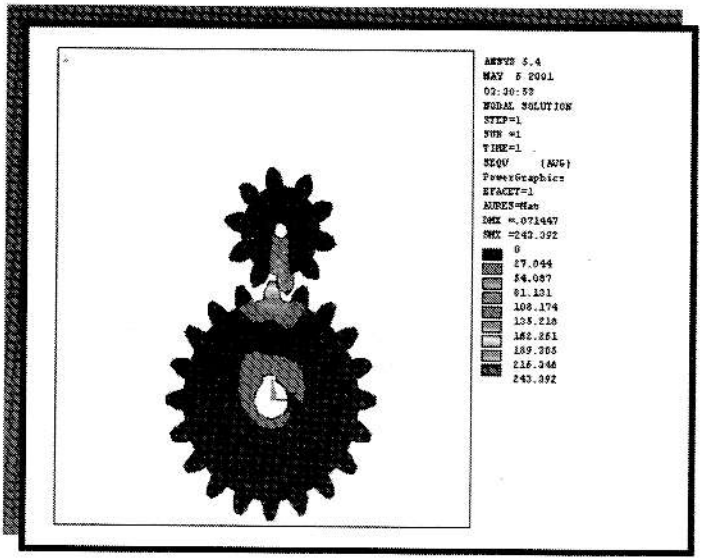

Fig (10) Von misses stress analysis

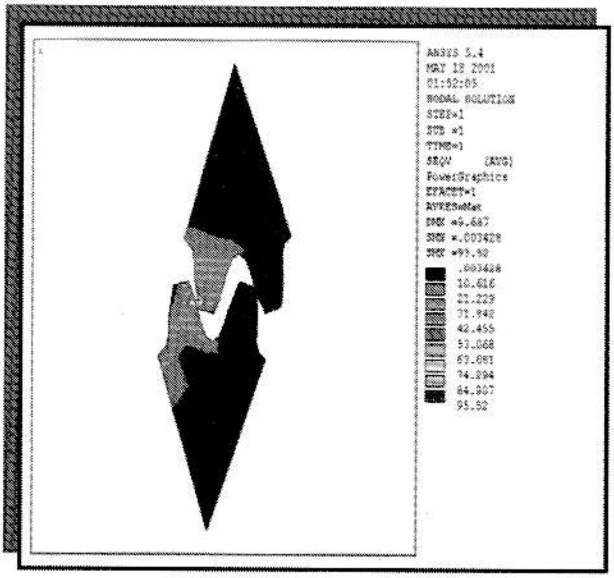

Fig (11) Von misses stress analysis for double pair of teeth in contact

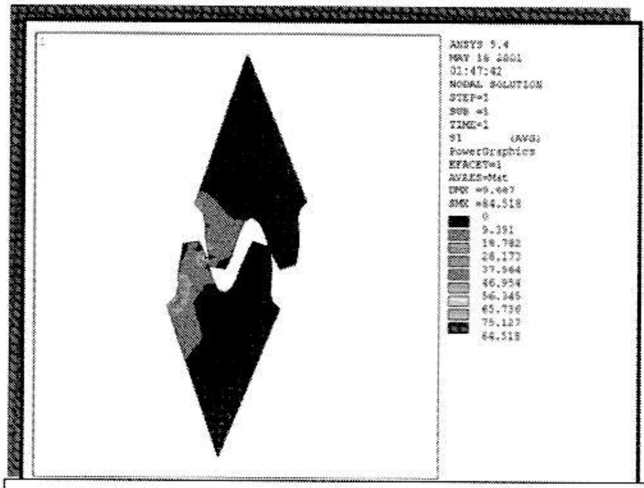

Fig (12) Principle stress analysis for double pair of teeth in contact

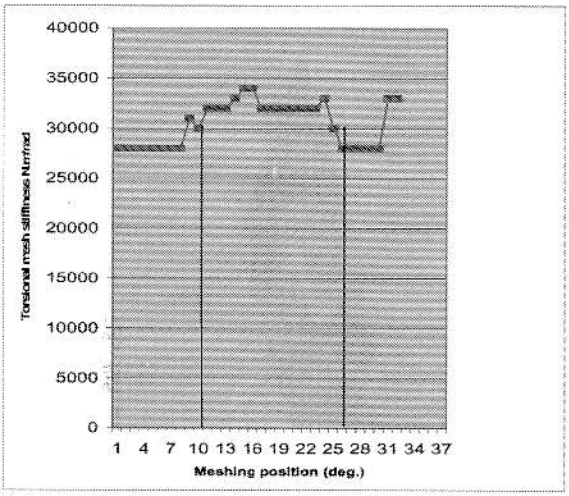

Fig.(13) Torsional mesh stiffness during one tooth mesh cycle

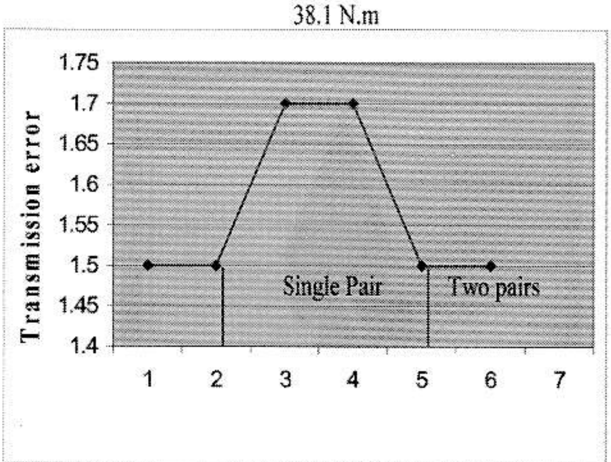

Fig (14) Transmission error during one tooth mesh cycle with applied Torque 38.1 N.m

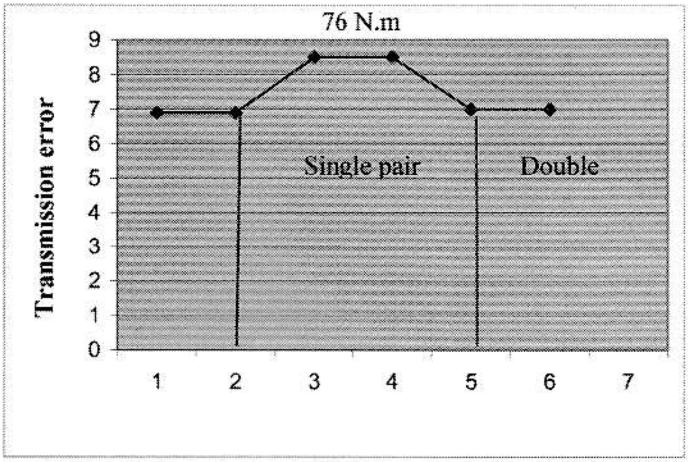

Fig (15) Transmission error during one tooth mesh cycle with applied

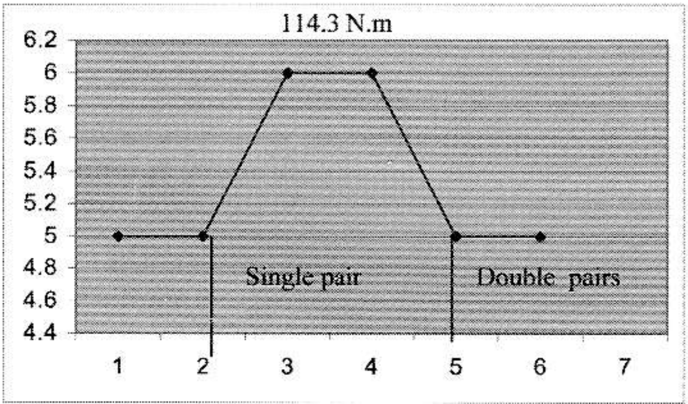

Fig (16) Transmission error during one tooth mesh cycle with applied Torque 114.3 N.m

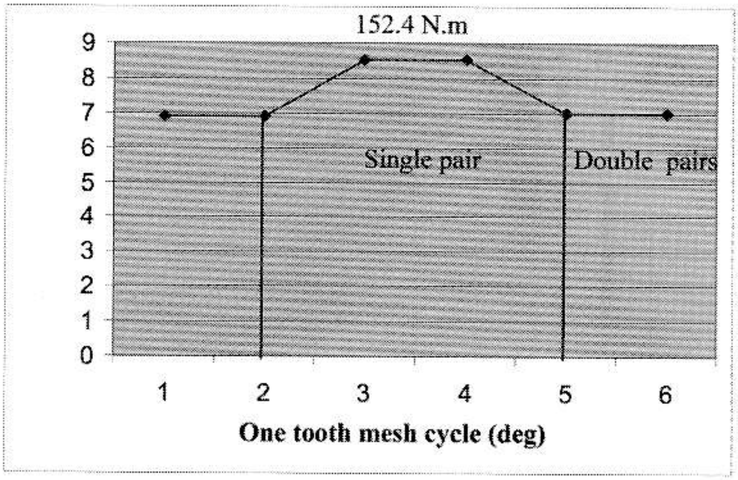

Fig (17) Transmission error during one tooth mesh cycle with applied Torque 152.4 N.m