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STRESS ANALYSIS IN A HELICAL GEAR OF A TRANSMISSION BOX BY THE PHOTOELASTICITY METHOD

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Abstract. *Digital photoelasticity is an important optical metrology for analysis of stress and deformity using digital images of the total field. Advances in data acquisition, digital image processing, storage and procedures for pattern recognition technique allows the use of computer-assisted automation to improve digital photoelastic technique. The objective of this research is to use this technology to evaluate the stress distribution in the third gear of a Palio Fire 1.4 8v model gearbox Fiat 2005. In order to get meaningful results, you need to make a replica resin gears and have many photographs of them under stress due to a load cell in a polariscope.*

Keywords: *photoelasticity;photoelastic stress analysis;optical measurement systems;optical interferometry;experimental techniques*

1. INTRODUCTION (TIMES NEW ROMAN, BOLD, SIZE 10)

Most systems that transmit power between two rotating shafts using gears, as these are the most effective and efficient in this type of application. Gears, although simple, are the basic elements of running various mechanical systems, these systems must operate for as long as possible without maintenance to lose yourself less time.

The stress analysis in the gears by the photoelasticity digital techniques allows obtaining information about the stresses distributed on the geometry of the element, when subjected to stresses coupling being able to determine the positions of the teeth, which occurs most of the wear. The knowledge of the stress fields acting on gears studies helps to improve the designs of gears and apply them more efficiently extending its useful life. The main advantage of the use of photoelasticity, relative to other experimental procedures, it is possible to determine the efforts and deformations of various types of materials and at any point of interest.

The objective of this research is to use this technology to evaluate the stress distribution in the third gear of a Palio Fire 1.4 16v model gearbox Fiat 2004 and to determine what point of the gear suffers more wear. It is intended to use a program that has as its operating principle, the phase shift (Phase-Shifting) technical and unpack (unwrapped technique) in color photoelastic fringes produced by white light and compare the results with the simulation program made in elements ANSYS finite.

In this work, the worm gear to be analyzed with the help of photoelasticity has Number of teeth = 22, pitch diameter = 56 mm, module = 2.5 mm, pressure angle = 14º30', helix angle = 32°, addendum = 62.5 mm, diameter of the base circle = 49.6 mm, Dedendum = 48 mm.

2. GEARS

The gear boxes of automobiles are compound gear trains. The transmission system enables the transmission ratio between the engine and the differential change as the vehicle speed increases or decreases. They shifting ensures that the engine maintains its rotation next band performance. And the operation box receives the engine speed and transmits this rotation to the differential. This, in turn, transmits the rotation to the vehicle wheels. Between the motor axis and the axis of the gearbox there is a clutch that can isolate one axis from the other. (KODA, 2009)

Gears are rigid elements used in order to transmit torque and angular velocity wheelbase for various purposes. The gears can have the following shapes: cylindrical, conical, helical or straight. In these teeth are made possible high efficiency in transmitting rotation, because there is no slippage between the teeth at the pitch diameter for the gear.

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These elements allow, therefore, changes of speed and torque with minimum energy loss. The change of speed and torque is made at the ratio of the pitch diameters. When the speed increases, the torque decreases or opposite. Thus, a pair of gears, the greater will transmit a higher torque and lower rotation.

Helical gears have teeth inclined with respect to its axis of rotation at an angle of propeller, "FIG. 1". The helix angle can typically range from 10 º to 45 º. This angle should be the same for the pair of gears, one gear but must have the right angle, and the pair should have its angle to the left. . Can be used in the same applications of cylindrical gears and also to transmit motion between non-parallel axes. Despite the more complex geometry are quieter due to gradual tooth contact during meshing. Appear in this type of gear, due to the inclination of the teeth, bending moments and axial forces in that there are spur gears (Shigley, 2005).

The transmission system of the third speed Fire 1.4 comprises a pair of parallel helical gear type. These types of gears meshes with a combination of bearing and sliding contact begins at the end of the tooth width and crossed by sweeping his face. In spur gears that contact between teeth occurs all at once along the line that crosses the face of the tooth at the time of contact between teeth. This difference between the contact teeth causes the parallel helical gears are quieter and with less vibration and are capable of transmitting high power and to be silent allowing a greater listening comfort inside the vehicle. (Norton 2004)

Figure 1. Illustration helical gear

There are two failure modes that affect the teeth of gears: fatigue fracture due to bending stresses at the root of the tooth and surface fatigue of the tooth surface. A pair of gears properly designed should never fracturing a tooth in normal (unless you have to work with loads greater than the design, but one should expect them will to fail sooner or later by wear mechanisms. (Norton 2004)

3. PHOTOELASTICITY

Generally the materials have a property known as elasticity. This property allows the elastic bodies deform When Subjected to forces and return to its original shape When the forces are removed. The return of the equipment to its original form Occurs only if the applied forces of not Exceed the limit of elastic resistance of the materials.

The main stresses are referred to in the literature the σ1, σ2 and σ3 are defined and the maximum the usual stresses acting at a point of the materials. In plane stress toward tension "z" is negligible (σ3 = 0). In this situation, the voltages are contained in planes parallel to the plane containing the effort requested structure. The mathematical formulas developed in the field of photoelasticity revolve around mathematical relationships involving the σ1-σ2 difference to the birefringent properties of materials and the wavelength of the light used in the experiments (Quinan, 2005).

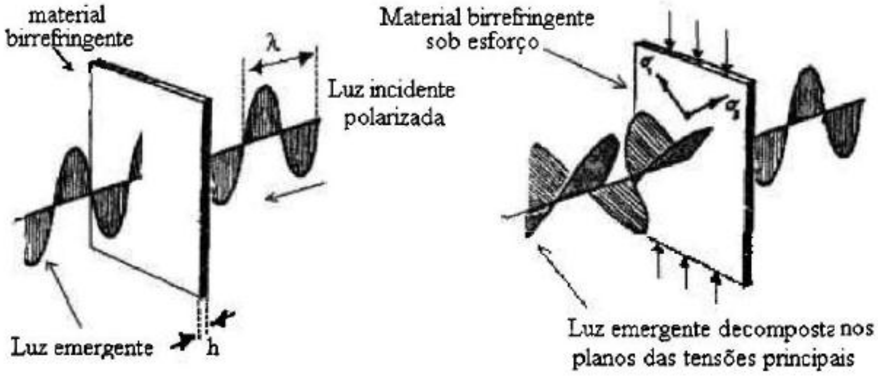

Figure 2. The phenomenon of birefringence mechanical

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The fundamental principles of photoelastic technique are derived from theories about electromagnetic waves, the phenomenon of birefringence temporary refraction of transparent materials, light polarization, among others.

The referred birefringent materials have the same-optical characteristics in all directions when free of tension – they provide optical isotropy. However, when these materials are subjected to anisotropic stress, the presenting characteristics are similar to those of the crystals. The property of optical anisotropy remains efforts while the materials are kept on the back to being optically isotropic when efforts are taken on it, the Figure 2.

Thus, when the birefringent materials are subjected to loads and viewed through polarized light exhibit stress field in the form of isochromatic fringes. These fringe patterns are linearly proportional to the difference between the principal stresses (Quinan, 2005).

Using the concepts of plane stress ($\sigma 3 = 0$) and two-dimensional models of thin birefringent constant h, the principal stresses $\sigma 1$ and $\sigma 2$ are related as follows, and according to Brewster's Law, $n1 - n2 \approx \varepsilon 1 - \varepsilon 2$:

$$n_1 - n_2 = k_0(\sigma_1 - \sigma_2) \tag{1}$$

Where:

- $k0$ = stress ratio optical
- $\varepsilon 1$ and $\varepsilon 2$ = principal strain

The techniques used in digital photoelasticity consist in inserting a birefringent model subjected to efforts polariscope. The fringe patterns related to the difference between the principal stresses and their directions in the sample are captured by a digital camera, processed and displayed by a computer (Magalhães, 2011).

With the techniques of digital image processing is possible to obtain quantitative data on the photoelastic parameters.

4. DEVELOPMENT

The development of project was carried out according to the following stages:

- Initially the model was done in resin.
- Simulation using the ANSYS finite elements.
- Photos.
- Comparison of results, finite element and photoelasticity.

4.1 Model in Resin

Silicones are used for making molds because are efficient, fast workability, low cost and enable fabricating parts of various formats, from simple to complex geometries. However, the silicone has a low durability and do not guarantee accuracy in measurements, ideal for making molds for prototype parts that not requiring precision in the final measures. An example of the silicone mold shown in Figure 3.

Figure 3. Mold Silicone

The process begins by sticking the piece with a instant glue in a box of paper, with dimensions slightly larger than the piece. This process is done so that the silicone doesn't to stay between the part and the box, allowing a better finish

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mold. Prepare the silicone in the proportions indicated by the manufacturer and put about the piece to cover it completely, as shown in Figure 4, wait it to dry for about an hour and retires the piece prioritizing the silicone mold. The surface of the silicone mold can't have fails as it is the negative part that will be used for the tests.

The silicone is a flexible material, it can’t ensure that mold walls to ensure relatively high support resin model so that it has the same dimensions as the original part. This problem can be solved by placing epoxy resin to form a shell around the silicone mold, providing necessary support to the silicone mold and ensuring that the measurements of the model will to be equal to those of the part used in the manufacture the mold.

With the silicone mold ready begins the process of preparing the resin. In the manufacture of resin models, as well as the silicone molds is of fundamental importance that the surface being worked on is level, as this avoids that parts are not uniform. The Epoxy resins shown in Figure 5 and the silicone POLIPOX used are manufactured by a company specializing in polymer technology.

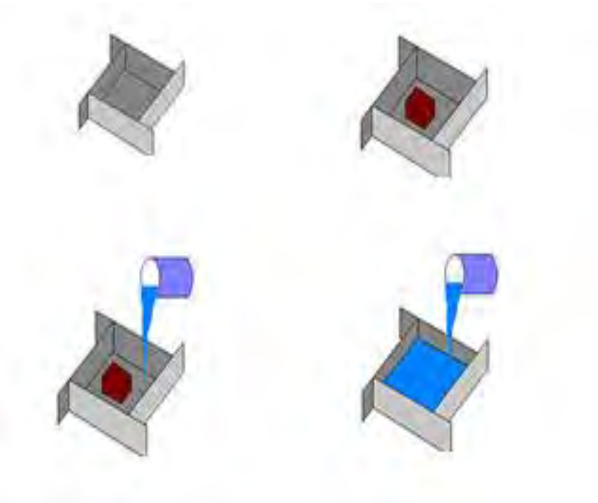

Figure 4 - Method of manufacturing silicon molds

The resin 3121 is provided in two types rigid or flexible, and rigid used in this work for making Gears blueprint due to the magnitude of the effort applied to the model. The preparation of the model is to estimate the approximate volume that takes part in the mold, thus obtaining the amount of resin required to fill the mold. The resin must be mixed with hardener in the ratio 2:1, the mixture should be well taken all the material handling and always observing the sides and bottom of the container until obtaining complete mixing and uniform transparent. The mixture must pass the cloudy appearance (not mixed) to look completely transparent (well mixed). If the mixture is not well made, the model will look with a matte appearance and sticky, impairing their optical properties.

Figure 5 - Epoxy resin of Polipox

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After mixing should be poured into the liquid in the center of the mold and let it drain to the edges, the mixture does not completely fill the mold can be used a spatula or other object to complete the missing area for always pushing the center edges. If some bubbles remain after the mixing process, they can also be removed with the aid of a toothpick.

The phase locking prior mold is one of the most important, because if not done can harm the desired end result. The mold must be cleaned using a cleaning and degreasing dust and other impurities must also be removed without the use of rags or cloths, as they can damage the silicon, using only water to it. In the process of curing the resin, which lasts approximately 24 hours, you should protect it from contact with dust or other substances that may be deposited on the model, adhering to it and damaging its optical properties.

4.2 Simulation using the ANSYS finite elements.

Then, it's necessary the following steps:

- Take all measures and data from the gears.
- Draw the gear in the SolidWorks program.
- Import the drawing to ANSYS.
- Simulate and analyse the results.

4.3 Photos.

To take the pictures, simulates a system where loads are applied. The great difficulty in this work is to know the load applied. The photos should be taken with the system of gears turning, as this is not possible, try to apply tension at its ends and analyze the tensions between the gear teeth.

The photos of the resin parts are taken by a digital camera by applying voltages at the ends of the gears via a bracket and observing the fringes of tensions in the polariscope (Fig. 6). The photos must be taken varying phase angles and must observe the light and dark phase.

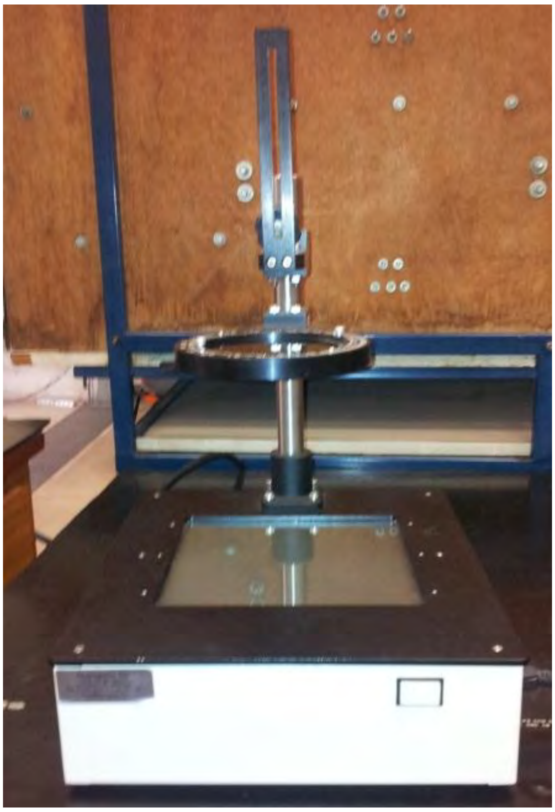

Figure 6. Polariscope

The voltage fringe of material varies in time and also dependent on the environmental conditions, it is therefore necessary to calibrate the polariscope at the time of testing. This calibration is accomplished through the analysis of a single birefringent material in which the stress field is known. Despite the existence of various materials where the stress fields are known in the photoelastic analysis is commonly used in a circular disc diametral compression. The circular disk (Fig. 7) is preferable because it is compact, easy to manufacture and can submit it to compressive stresses without many complications. The stress field cannot be obtained by the principles of the Strength of Materials, but can be obtained through the use of the principles of the theory of elasticity (Ramesh 2012).

Figure 7. Circular disc for calibration polariscope

In the optic calibration of the material was used a circular disk under loads of compression diametrically opposites. The circular disk have diameter of 55mm e thickness of 6mm. The disk under compression loads is shown in Fig. 8. A load of 20N was applied in the model to find the value of the factor of optic calibration Fσ.

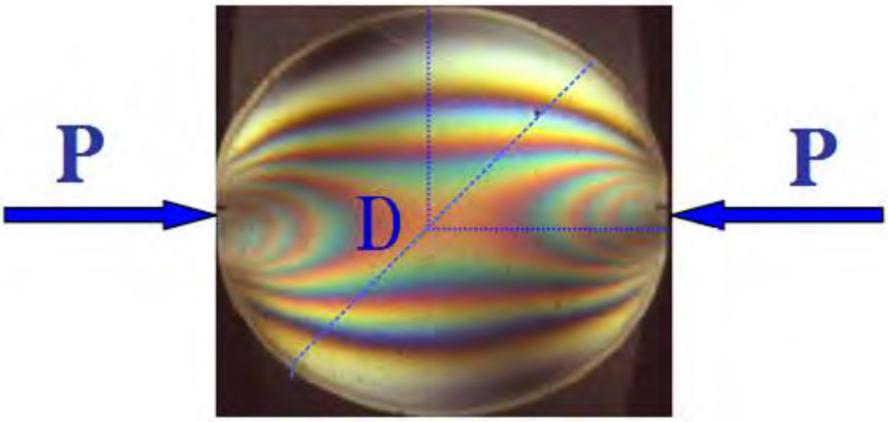

Figure 8. Circular disk under compression loads

Viewing the fringes pattern in the model under efforts through of the circular polariscope, found the fringe order N observed in the center of the disk is 2,51. Using the Eq. (2), the value of Fσ is, about, 0,37N/mm.

$$F_\sigma = \frac{8P}{\pi D N} \qquad (2)$$

Onde:
P – Applied load;
D – Diameter of the disk;
N – Fringe order in the center of the disk.

5. RESULTS

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The stresses acting on the helical teeth of the gears at the time of initiating contact can be analyzed by the techniques of two-dimensional and a photoelastic element using the 2D finite element method. The photos in Fig. 9 show the pattern of fringes for some values of moments applied on the teeth. In Fig. 10 are shown the results obtained from the stress analysis by finite element method.

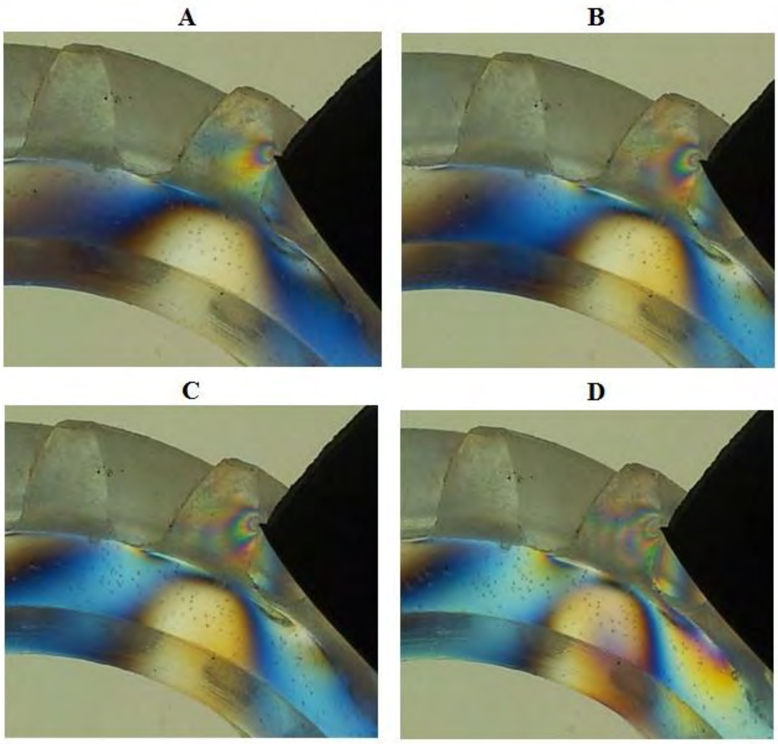

Figure 9. Fringe pattern for different values of moments applied

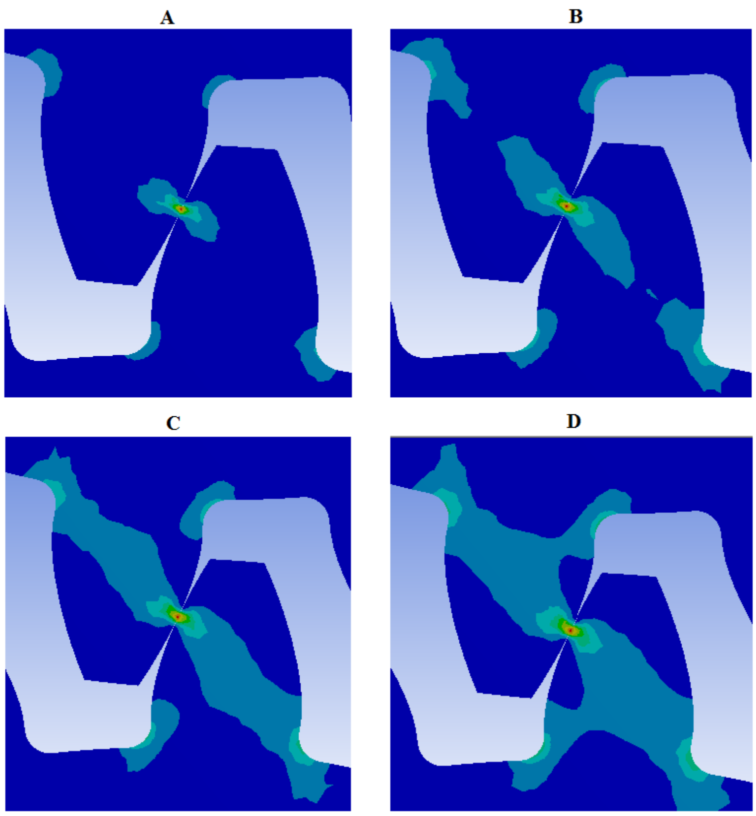

Figure 10. Results obtained by the finite element method

The stresses on the photoelastic model were obtained with the aid of software developed in MATLAB using the Phase-Shifting technique and Unwrapping technique. The maximum stresses acting in photoelastic models and gears simulated in Ansys, are located at the contact point during the engagement. And the stresses values obtained at this point are shown in Tab. 1.

Stress by photoelasticity technique [MPa]	Stress by FEM [MPa]
63,00	64,56
66,42	67,80
70,71	70,93
73,28	75,23

Table 1. Value of stress in contact point

6. CONCLUSION

The experimental values agree with the finite element method, since the maximum error is only 2.66%. During the engagement, the higher stress is located at the contact point between the teeth. The higher the torque value, the greater the stresses at the contact points and at the root of the tooth. The stress at the contact between the teeth should be as small as possible to wear reduce and increase the life of the gears.

7. REFERENCES

KODA, Fábio. *Estudo da fadiga de contato em engrenagens cilíndricas de dentes retos*. 2009. 187f. Dissertação (Mestrado) – Universidade Tecnológica Federal do Paraná, Programa de Pós-Graduação em Engenharia Mecânica e de Materiais, Curitiba.

MAGALHÃES, Cristina Almeida. *Análise de novos métodos numéricos na técnica fotoelástica digital usando o deslocamento de fase.* 2011. 350 f. Tese (Doutorado) – Pontifícia Universidade Católica de Minas Gerais, Programa de Pós-Graduação em Engenharia Mecânica, Belo Horizonte.

NORTON, Robert L. *Projeto de máquinas: uma abordagem integrada.* Porto Alegre: Bookman, 2004. XIII, 931p.

QUINAN, Marco Antônio Dutra. *Uma metodologia para determinação do fator de intensidade de tensões causado por tensões térmicas utilizando a fotoelasticidade*. 2005. 163f. Tese (Doutorado) – Universidade de São Paulo, Instituto de Pesquisas Energéticas e Nucleares, São Paulo.

SHIGLEY, Joseph Edward; MISCHKE, Charles R.; BUDYNAS, Richard G. *Projeto de engenharia mecânica*. São Paulo: Bookman, 2005 960 p.