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Infrared Thermographic dynamic analysis and Non-Destructive Testing (NDT) for camshaft diagnostics

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Abstract

This research is aimed to examine through Non-Destructive Testing (NDT) the material behavior under in-use conditions of an internal combustion engine (ICM) camshaft. The material composition is identified by X-ray fluorescence spectrometry (XRF) approximated to a low carbon 1025 semi mild steel through ASTM E1085 2016, ASTM E3-2017 and ASTM E-407. For wear identification, several tests that can be applied to a camshaft were performed among which we can mention: visual inspection (VT) through UNE-EN 13018, Infrared Thermographic (IRT) with the specifications of ISO 18434-1, Penetrating Dyes (PT) according to ASTM E 165-02, Ultrasound (UT) based ASTM A388-19, the analysis is performed on the surface of the cams and support journals of the camshaft. To determine the reliability of the results, an analysis of the tests described in the same area is performed, the method of greater scope is ultrasound for having greater inspection coverage; the design was validated by CAE Computer Aided Engineering software in which simulations and finite element mechanical analysis were performed to determine the safety of the system.

Keywords: Camshaft; Spectrometry; Infrared Thermography; Non-Destructive Testing; Metallographic.

1. Introduction

The camshaft is in charge of allowing the opening and closing of the valves by means of eccentricities in an internal combustion engine [1], the cams can be cast or forged together with the camshaft, this makes its rigidity and residence to be high in order to absorb the bending stresses, torsion and vibrations that are produced during its operation [2], in order to obtain the required hardness on the surface of the cams by induction or other similar methods and ensure resistance to wear [3]. In fact, a pearlitic structure is required in the journals and the shaft core to ensure toughness [4,5]. The shaft is subjected to cyclic loads and torque causing various defects such as: discontinuities, structural or dimensional anomalies, homogeneities, which according to the design can build a planar surface defect, subsurface or internal defects for the identification of these defects are performed nondestructive tests that allow examining the shaft without altering the chemical or physical state of the material [6]. In the automotive area, measuring instruments such as dial indicator, caliper and outside micrometer are commonly used, and to a lesser extent the penetrant dye test, to detect defects in steel, non-traditional but very effective tests such as infrared thermography and ultrasound are applied [7]. Infrared thermography is used in the automotive area (engines and spare parts, structure, bodywork, steering and transmission elements), this method will allow to obtain images of the heat distribution of the axle surface and to identify the specific place where the greatest fatigue occurs, to quantify the energy loss of the component [8,9].

2. Material Characterization

For the non-destructive testing analysis, the camshaft material Fig. 1 literal (a) is determined through the ASTM EN 1085-16 standard applying the X-ray fluorescence spectrometry (XRF) method with the use of the OLYMPUS DPO2000-C equipment by energy dispersive (ED) of materials at a temperature of approximately 21, 6 [◦C], and with an energy of 40 [keV] which presents 98.94% of Iron (Fe) and alloying elements such as Cobalt (Co) , Manganese(Mn),

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Copper(Cu), Molybdenum (Mo), Silicon (Si) [10]. In addition to complete the results a metallographic analysis (MA) was performed under ASTM E3-2017 and ASTM-407 using the OLYMPUS BX41M-LED equipment, through the quantitative study it was determined that it is a semi mild steel with low carbon content 1025 observe Fig. 1 literal (b) representing the metallography of the metal at a 1000X view with 4% Nital chemical attack obtaining a low percentage of Carbon (C) present in the composition of the material as shown in Table 1 [11].

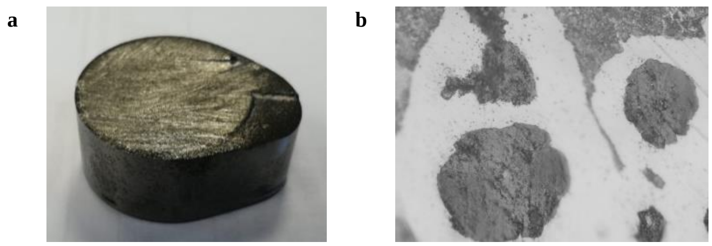

Fig. 1. (a) Chevrolet Vitara 3P 1500 cm^3 4T Section, (b) Micrograph of a cam at 1000 X

Table 1. Sample Chemical Analysis

	Elements						
Material	Fe	Co	Mn	Cu	Mo	Si	C
ASTM 1025 [%]	99,48	-	0.3 - 0,6	0,02	0,02	0,029	0,2 - 0,28
Experimental by (XRF), semi mild steel 1025 [%].	98,94	0,38	0,33	0,029	0,053	0,033	0,247

3. Methods

To determine some physical characteristic or to evaluate the integrity of the material present in the camshaft of an internal combustion engine it is necessary to apply non-invasive techniques, the visual inspection test of the camshaft provides an agile diagnosis [12]; penetrant inks are used to detect and identify discontinuities open to the surface (erosions, cracks, pores, etc.) in metallic or non-metallic materials other than pores [13,14,15]; infrared thermography as a non-conventional method obtains images of the heat distribution on the surface of the camshaft by means of radiation heat and temperature, consequently it is not necessary physical contact with the element and allows readings in real time [16], ultrasound by introducing an elastic wave and producing echoes to establish the location of the discontinuity while obtaining high precision in the determination of surface and subsurface discontinuities reflector with high sensitivity which allows an easy interpretation of data [17]. Through these tests it is feasible to find defects in the camshaft of an I.C.M., see Table 2.

Table 2. Main non-destructive testing methods applied in camshaft testing

Method	Technique	Regulations	Equipment	Guidelines
Visual Essay	Direct Vision	EN 13018 API Article 9.6 ASME Section V, subsection A, article 9	Naked human eye	Surface preparation Minimum illumination and intensity 100 fc (1000 lx) Minimum viewing angle 30°. Human eye at 600 [mm] from the surface.
Infrared	Thermographic	ISO 18434 - 1	Fluke-Reability TiS60-17030620 Version: 6.0.86	Calibrated IRT quantitative chamber. Component at 80 or 95 ° C optimum temperature of an ICM.
Penetrant Inks	Colored	ISO 3452 ASME BPVC.V ASTM E165–02 ASTM A388-19	SKL-SP Penetrant AKD-S2 Developer	The Surface should range between 10 and 50 ° C and (50 and 122 ° F) Pre-cleaning, drying, penetrant application and dry developer application.

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Ultrasound	Transmission	MIL I-6866 ASTM E1417 EN 12668 EN 583	Olympus Epoch 600	Minimum illumination and intensity 100 fc (1000 lx). In metallic materials equal to or greater than 10 [mm] thick. Minimum frequency ranges from 1 to 6 [MHz]. Gain calibrated to a minimum of 2 dB

4. Tests

4.1. Visual Inspection Test (VIT)

The visual test consists of the detailed observation of the camshaft at a distance no greater than 600 mm and at a minimum distance of 30º from the human eye as mentioned in the ASME code section V, subsection A, article 9 and at a minimum illumination and intensity of 1000 lx [16], in such a way it is necessary to calculate the speed of light in the considered medium in this case steel *(v_{acero})* obtaining 119916983,2 $[m/s]$, with a refractive index *(n_{acero})* of 2,5 subjected to a speed of light in vacuum *(c)* de 299792458 $[m/s]$, according to the Eq. 1.

$$v_{acero} = c/n_{acero} \tag{1}$$

4.2. Infrared Thermographic Test

For the analysis of this test, the Step Heating technique [17] was implemented, the camshaft is heated at low revolutions for thirty minutes until reaching the optimum engine temperature of 80º C to 95º C, to monitor the cooling of the camshaft and analyze the defects by heat transmission by radiation, the infrared emission used with the equipment is approximately 8um wavelength by Stefan Boltzmann's law with *Eq. 2,* and some of the environmental factors detailed in Table 3, it is possible to calculate radiation heat in movement of the analyzed part obtained 21,469 W/m.

$$q_r = Ae\sigma(T_S^4 - T_{atm}^4) \tag{2}$$

Table 3. Factors for thermodynamic analysis

Loads	Value
Emissivity ($\boldsymbol{e}$)	0,85
Cam contact area (Mb)	0,0449 [m]
Relative Humidity (ϕ)	50 [%]
Surface temperature ($\boldsymbol{T_s}$)	368,15 [° k]
Atmospheric temperature ($\boldsymbol{T_{atm}}$)	291.15 [° k]
Stefan's Constant (σ)	5,6703*10^{-8}[W/m^2k^4]

a b

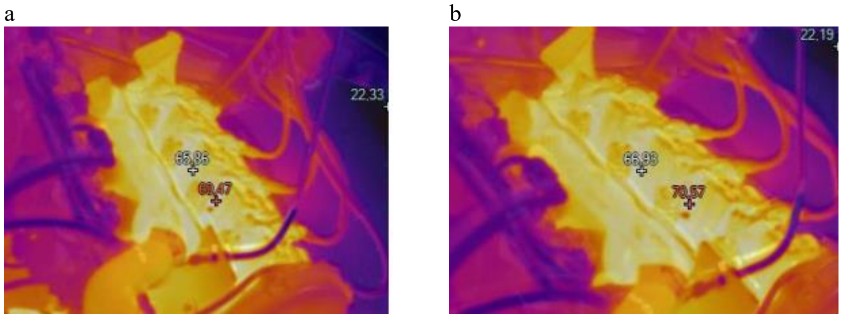

Fig. 2. (a) Infrared Thermal Infrared Camshaft Test

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4.3. Penetrant Liquid Test

For the analysis of this test was performed with the support of the MIL-I-6866-04 standard, with visible penetrant, type C - removable solvent. The temperature is 18 [º C]. As the camshaft is made of 1025 carbon steel, according to the standard, the penetration time and revelation to obtain an adequate capillarity is from five to ten minutes. For the removal of the penetrant liquid apply the cleaner with the rubbing technique and check the removal of excess penetrant Fig. 3 literal (a), drying after the application of the developer through this method the part is inspected as shown in Fig. 3 literal (b) the open discontinuities on the surface of the shaft.

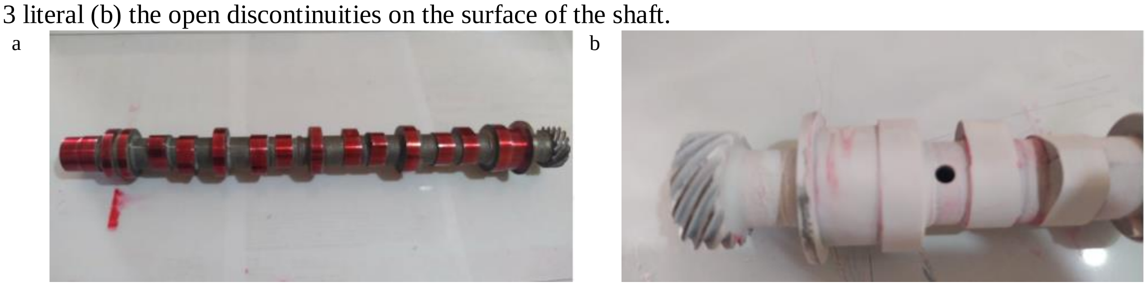

Fig. 3. (a) Camshaft with penetrating ink (b) Test applied to cams and supports

4.4. Ultrasound Test

With the Olympus Epoch 600, phased array mode and straight probe, the camshaft is examined and the sound propagation velocity 6320 $[m/s]$ is set to identify defects in the cam shaft and inner bore. Fig. 4 shows the inspection points with an angle of -30° to 30º, defines the longitudinal wavelength equivalent to 5091,75 [m/s], the radical of Young's modulus *(E)* for 1025 steel [18].

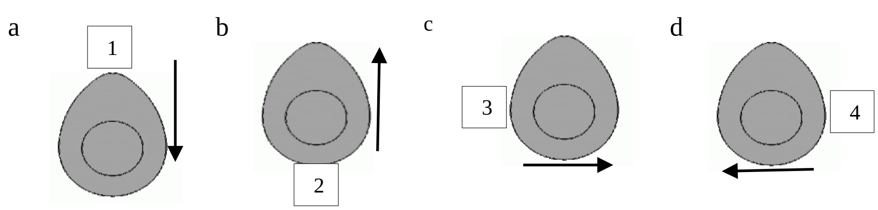

Fig. 4. (a) Inspection points of cam 1, (b) Inspection points of cam 2, (c) Inspection points of cam 3 and (d) Inspection points of cam 4.

5. Results

In the different parts of the shaft (camshaft) of analysis, the location of the four types of defects is determined and the effectiveness of the four methods used for diagnosis is compared. The visual inspection method is used on the surface of the shaft, however, there are no cracks, while the ultrasonic method did not show the existence of an internal crack. To analyze a camshaft, it was determined that the most efficient method is the penetrating inks, detecting minimal discontinuities. Table 4 shows the lengths that were analyzed with the ultrasound method:

Table 4. Ultrasound evaluation results

Inspection Points	Length 1 [mm]	Length 2 [mm]	Length 3 [mm]	Length 4 [mm]	Length 5 [mm]	Defect
1	8,14	15,91	24,51	35,14	37,12	No
2	1,74	12,71	21,37	29,78	37,07	No
3	1,08	10,24	21,13	30,12	31,18	No
4	1,12	9,85	18,93	29,15	30,96	No

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5.1. Theoretical Stress Model Analysis

For the research several study parameters have been taken into account with which the CAE software will calculate the different aerodynamic parameters of the camshaft, among the variables of interest are the following: Poisson's coefficient *(μ)*, shear modulus *(G)*, elastic modulus *(E)*. To perform these calculations the software requires the data shown in Table 5 [19].

Table 5. Camshaft design parameters with ASTM 1025 steel

Variables	Units	Value
Poisson's ratio		0,29
Shear modulus	GPa	82
Elastic modulus	GPa	215
Engine temperature	◦C	85
Atmospheric pressure	Pa	101325
Steel density 1025	kg/m^3	7900
Average camshaft speed	rpm	3500
Camshaft cross-sectional area	m^2	0.726337

5.2. Dynamic Analysis of the component

With the pressure supported by the camshaft, a CAE simulation has been generated using the Solid Works software see Fig. 6 literal (a) with the working pressure of 18.84 [MPa] and with a determined chemical composition of 1025 steel, various wear points are applied, which are exposed to contact, obtaining a safety factor of 6.2, this is a dimensionless result that induces the shaft to work optimally, taking the strength of the material and the maximum effort that is required to cover, see Fig. 6 literal (b) [20].

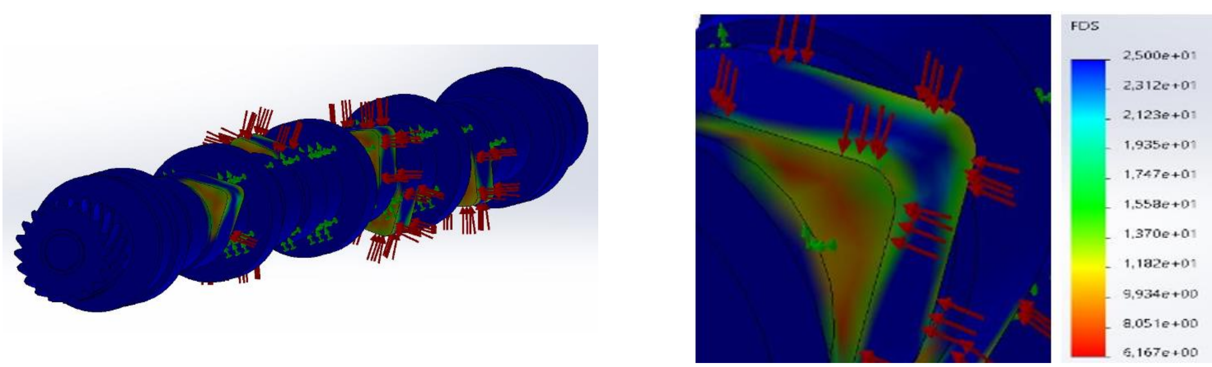

Fig. 5. (a) Camshaft Simulation, (b) Section of a cam

A summary of the aerodynamic values shown in Table 6 was used to generate the allowable safety factor and power factor analysis.

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Table 6. CAE Simulation Results

Variable	Values
Maximum Pressure [MPa]	18,84
Maximum Force [N]	866,04
Poisson's Coefficient	0,6213
Factor of Safety	6,2
Power [W]	51081,50

6. Conclusions

NDT results show that visual inspection can detect defects up to 4.5 [mm], infrared thermography covers a range of 2.5 [mm] in length, penetrant inks reveal flaws from 2 [mm] and up and does not detect all cases of defects, ultrasound despite having a greater penetration range, is limited to evaluating the cam surface.

According to the analogy made, it is determined that the penetrant dye test has a greater efficiency when performing an inspection on a camshaft having a greater scope of inspection than the others, detecting the four types of defects found in the camshaft does not present pitting, no cracks simply discontinuities, determining that this component does not receive greater wear.

The modeled camshaft meets all the parameters of the requirements that were established for the design, so the component is safe and reliable and will not fail to function when the pressure exerted on it does not exceed 18.84 [MPa].

References

[1] J. Alvarez and I. Callejon, Internal Combustion Engines, Four-Stroke Distribution, Camshafts, pp. 448-456 (2017).

[2] A. Rovira and M. Muñoz, Internal Combustion Engines, Injection System, pp. 428-433 (2015).

[3] E. Romero Abrasive and impact wear resistance analysis of high-alloy white cast irons, pp. 56-61 (2018).

[4] G. Fontecha and J. Díaz, ITECKNE, Camshaft failure analysis of an inline six-cylinder engine, Volume 6, No 1, pp. 639-645 (2009).

[5] M. Romanyuk and E. Brandaleze, Effect of cementite destabilization on the development of high levels of Mechanical Strength in Pearlitic Steels, Advances in Science and Engineering - ISSN: 0718-8706, pp. 5002 (2016).

[6] L. Saenz, Introduction to Non-Destructive Testing, Universidad de las Fuerzas Armadas ESPE, first electronic edition. pp. 14-78, (2020).

[7] S. Millan, Machining Processes, Mechanical Measuring Instruments, (2015) pp. 18-24.

[8] M. Cañada and R. Royo, Infrared Thermography ITC, Introduction to Non-Destructive Testing, Inspection Techniques, pp. 50-65 (2016).

Available online at www.sciencedirect.com

ScienceDirect

materialstoday: PROCEEDINGS

[9] Min, N., Li, W., Li, H. & Jin, X. (2010). Atom probe and Mossebauer spectroscopy investigations of cementite dissolution in a cold drawn eutectoid steel. Journal of Materials Science and Technology, 26 (9), pp. 776-782. doi.org/10.1016/j.mspro.2015.04.164

[10] Norma ASTM E1085 – 16, Standard Test Method for Analysis of Low-Alloy Steels by Wavelength Dispersive X-Ray Fluorescence Spectrometry, pp. 6 (2016).

[11] Norma ASTM E3 – 11, Standard Guide for Preparation of Metallographic Specimen, Active Standard ASTM E3 Developed by Subcommittee: E04.01 (2017).

[12] G. Miretti, D. Perín, F. Tommasini, M. Puchaleta and O. Ramos, Automated inspection by non-destructive acoustic resonance testing for the detection of flaws in metal-mechanical parts, 16th International Congress on Metallurgy and Materials SAM-CONAMENT, pp. 568-573 (2016).

[13] UNE-EN ISO 3452-1, Non-destructive testing - Penetrant testing - Part 1: General principles (ISO 3452-1:2013, corrected version (2013).

[14] ASME BPVC.V, ASME Boiler and Pressure Vessel Code, Section V: Non-destructive Examination (2021).

[15] ASTM E 165 -02, Standard Test Method for Liquid Penetrant Examination (2002).

[16] ISO 18434-1, Condition monitoring and diagnostics of machines, Thermography Part 1: General Procedures (2008).

[17] ASTM A388 / A388M – 19, Standard Practice for Ultrasonic Examination of Steel Forgings, (2008).

[18] Ecuadorian Technical Standard NTE INEN 1323. *Motor vehicles, Bus bodies, Requirements*, pp. 2-11 (2009)

[19] Ecuadorian Technical Standard NTE INEN 1623, *Black or galvanized cold formed steel open profiles for structural use. Requirements and inspection*, pp.6 (2015)

[20] J. Restrepo, Camshafts and Valves OHV and SOHC vs DOHC (2019).