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EXPERIMENTAL INVESTIGATIONS FOR MODELLING THE THERMAL FATIGUE PHENOMENON IN MACHINES PARTS OF AUTOMOTIVE ENGINES

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ABSTRACT: The purpose of this paper is to present some experimental investigations for validate an experimental plant designed and built for study the thermal fatigue phenomenon that occurs in machines parts of internal combustion engines. Our study based under the concepts and methods used for thermal fatigue modeling under laboratory conditions presented in literature. To determine the thermal fatigue phenomenon we should know how resisting are these machine parts for being able to determine their estimated operation time by the number of operating cycles until the first cracks occur on their surface. Thermal fatigue study under laboratory conditions lead to the thermal fatigue resistance limits for different machine parts in the composition of internal combustion engines, specific to avoid cracking of the engine by optimizing the thermal regime and proposals for new materials with high resistance to thermal fatigue. The paper present the original measurement method developed by autors under an original experimental plant. This equipment allows modeling thermal fatigue of machines parts of internal combustion engines and it is property of the laboratory of "Industrial Mechanical Equipments" of the Faculty of Engineering of Hunedoara, University "Politehnica" from Timisoara, which is the subject of a patent registered at OSIM A/00439 number of 17.06.2010, published in bopi_inv_12_2011.
KEYWORDS: thermal fatigue, field, cycles, variations, model, temperature

INTRODUCTION

Fixed and mobile machine parts composing vehicle motor participate in the working cycle which is characterized by variations of temperature. They take a significant part of the heat developed inside the combustion chamber and transfer it to the cooler liquid. Thus, in certain areas of machine parts are created variable temperature fields. These temperature fields generate the occurrence of cyclic thermal stresses. The thermal stress values can be higher than the mechanical ones, and can lead to cracks on the surface and in the surface layer of the parts, specific to the thermal fatigue cracking phenomenon. This phenomenon is especially pronounced to the engines operating in very different thermal regimes, and where the part lifetime is higher. Heat load of combustion chamber generated thermal stresses which are the main factor limiting the performance and durability of internal combustuion engines, [1], [9].

Heating up and cooling cycles of the component parts of internal combustion engines can have different character. It is assumed [3] that heat strokes caused by high heating velocity are more damgerous than those that are caused by sudden cooling, which can be explained by lower durability of materials in high temperatures. For exemple, the piston heats up from an ambient temperature to working temperature in the time ranging from several dozen seconds to a few minutes, while the process of estabishing the average fild temperatures during engine transition between different load stages taken even less time, [3], [7], [10]. An average temperature fluctuation range depends on how and where the engine is used, [1], [3]. Frequent load changes are unavoidable in engines used to propel cars in city traffic, while long-distance truck, railway, naval and stationary engines have more stable work conditions, [3]. On the other hand, temperature variation field can cause cracking and leaking that disturbus or even makes engine operation impossible, [1]. Knowing the negative effects of the destruction of machine parts of internal combustion engines, in order to mitigate the causes of destruction by cracking of those parts we should make some thorough research, both theoretical and experimental.

Nowdays it is possible to calculate precisely the temperature distribution and internal stresses distribution in the fixe and mobile parts of the internal combustion engines by means of computer simulation. This can be done only if the boundary conditions are correcly estimated by measuring the temperature of real objects of similar geometry and working in similar conditions. Such measurements are difficult to take considering significant the working cycle of the internal combustion engines, which

generated cyclic variation in temperature with a speed of the order of seconds or even tenths of seconds, [3],[5].

The concept of thermal fatigue which is generated by variation temperature field is the subject of numerous studies, specific to various fields. In case of internal combustion engines, this phenomenon is mentioned in several works [1], [4], [5], [6], [7], [8], [10].

The basic criterion to characterize material behavior during variable cyclical thermal stress is the resistance to thermal fatigue [1], [3], [4]. This is determined and expressed by the number of thermal cycles suffered by a machine part until its surface cracks, [8].

Multitude of factors influencing the damage by thermal fatigue makes it impossible to develop a methodology to provide universal results consistent with the specific phenomenon actually performed. Actual heat strain can not be modeled in laboratory always, [1].

Some cycles require two separate programs application and synchronized modeling, one for temperature and one for deformation, [2].

The literature has not mentioned an indicator for estimating thermal fatigue resistance of materials that is applicable under conditions of temperature, both stationary and transient [1], [2], [6]. It is however known that thermal stress generated by variable temperature fields is proportional to the thermal gradient "Δt", decreasing along with increasing thermal conductivity 'λ', [1], [8].

For evaluation of thermal fatigue resistance of materials we must take into account the following factors [1], [8]: the number of cycles of temperature variation until noticeable cracks on the surface of the sample occur; the number of temperature variation cycles until it is destroyed and crack intensity.

Whatever test methods/testing, thermal fatigue phenomena research solves two problems, [1], [8]:

obtaining comparative data on thermal fatigue resistance in a group of materials with application to particular conditions of operation and exploitation;

collecting and processing experimental data through quantifying the quantitative evaluation of resistance to thermal fatigue to enable and ensure performance.

In the study of thermal fatigue, the determining factor is not the time nor the range in which requests are variable, but the number of load cycles until the fatigue cracking [1], [3]. Regarding the level of thermal stress, it will depend on: thermal parameters; physic-mechanical properties of materials and the change rate during temperature oscillations; and the appearance of stress state, geometry and constructive parameters of the item, [7]. For a part machine subjected to the stress caused by cyclic thermal fatigue, damage is always dictated by thermal values higher than mechanical ones, [7].

Based on these criteria, concepts and methods of the phenomenon of thermal fatigue treated in the literature, we designed and built up an experimental system for studying this phenomenon in case of fixed

and mobile machine parts of internal combustion engines. Designing and building an experimental facility allows us to study thermal fatigue resistance of main machine parts of vehicle engines. The experimental plant is the subject of a patent registered at OSIM A/00439 number of 17.06.2010, published in bopi_inv_12_2011.

The equipment allows modeling thermal fatigue of internal combustion engines and is property of the laboratory of "Industrial Mechanical Equipments" of the Faculty of Engineering of Hunedoara, University "Politehnica" from Timisoara.

THE EQUIPMENT USED AND THE CONDUCT OF THE RESEARCH

According to literature studies, qualitative method was chosen for laboratory modeling of thermal fatigue while testing, and thermal cycling was used to shape up the corrected Mason model and the corresponding hysteresis loop [2], [8]. In modeling real thermal cycles, the samples used are heated in a semicircle furnace with electric resistors and cooled off in different environments, such as air, water or ice. Based on these principles we designed an experimental facility for laboratory research of thermal fatigue which is presented in fig.1a,b, [8].
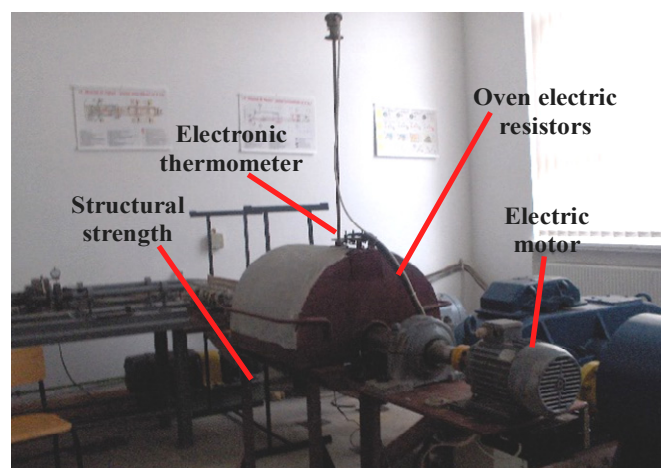

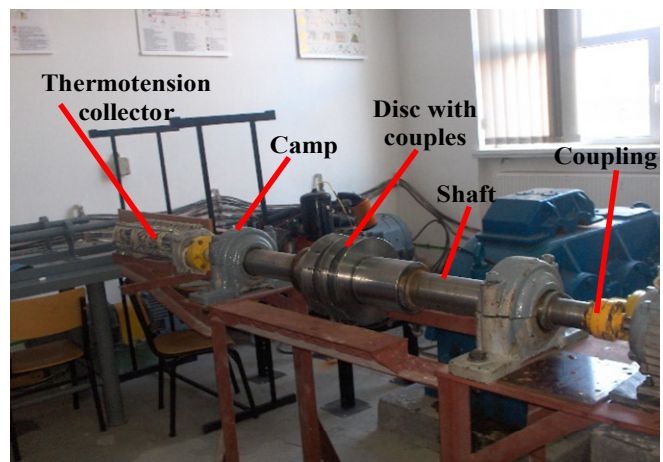Figure 1. Experimental plant to determine thermal fatigue resistance with sample heating furnace

Figure 2. Experimental ensemble without sample heating furnace

The constructive scheme of the installation to determine thermal fatigue resistance is shown in figure 3, where an electric motor 1 controlled by a static frequency converter 2 which drives the main

shaft 3 is assembled and mounted on the metal frame 4. Overlapping the samples mounted on the main shaft 5 there is a semicircular furnace 5 who is ordered to perform sample heating. At the end of the main shaft, as opposed to drive electric engine, there is the thermo-tension collector 6 which takes the electric signals from thermocouples whose wires are connected to the contact brushes rings.

Disk supports are mounted on the main shaft - intermediate 7 and sideward 8, with screwed samples mounted on the generators 10. Support disks are mounted according to the length amongst samples and to the intermediate bushes 11 and end bushes 12; system hardening is achieved by means of interior screws 13 and pressure collar 14.

Thermocouples are mounted placed on two opposite samples 15, with corresponding response inertia corresponding to operating cycle of the machine parts that were subject to thermal fatigue.
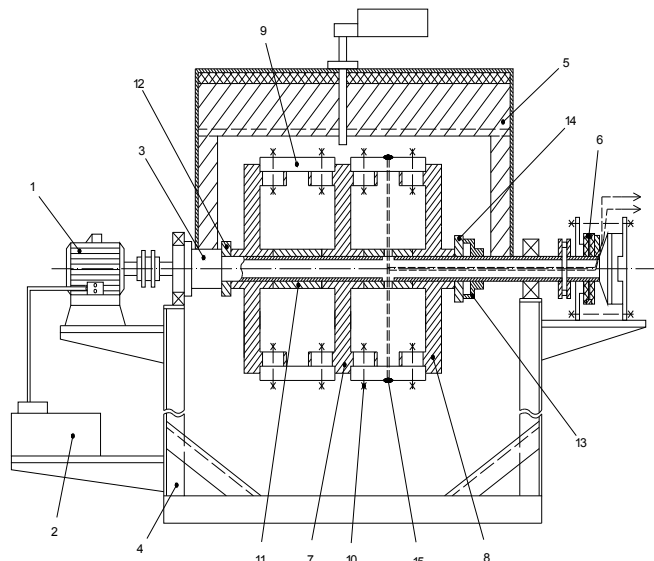

Figure 3. Constructive scheme
of experimental installation for determining thermal fatigue resistance of machine parts from internal combustion engines
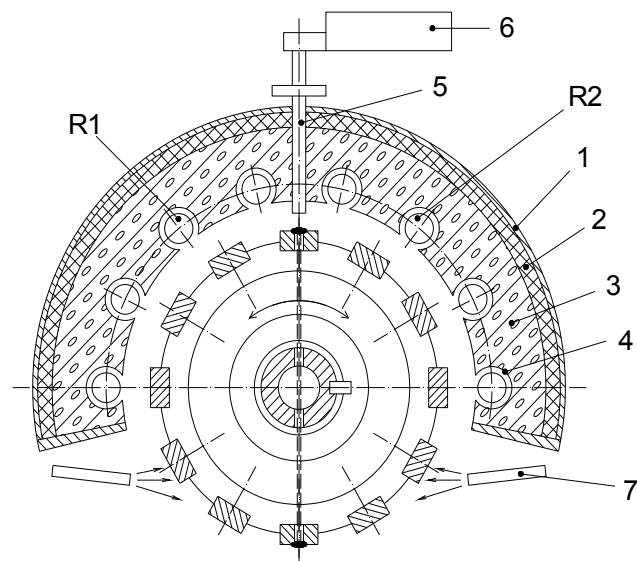

Figure 4. Cross-section of the plant laboratory experimental study of thermal fatigue

Figure 4 describe a section through the electric furnace for heating testing samples. The furnace is composed of a metal housing 1, lined with a heat insulating material 2, and the furnace is poured thermo steady concrete 3, with inner heat stream 4, which supports electrical resistors R1 and R2. Sample heating is enabled by a resistor with four loops, representing 90^0 of the circumference, or with both resistors comprising the entire area of the furnace, that is 180^0 of the circumference.

The furnace is fitted with a thermocouple 5 connected to an electronic thermometer 6, which helps us establish and maintain a certain temperature in the furnace through an automatic control, meanwhile 7 is the cooling of samples during experimental determinations.

The principle of investigations on experimental plant designed and built in two stages involve mounting two testing samples arranged opposite on the disk circumference of the thermocouple, and each are connected to a thermo-tension collector.

Figure 5 shows how we positioning the thermocouple on the sample and the sample size. In figure 6 is the connection made to a thermocouple inside the furnace to connect to the thermo-tension collector.
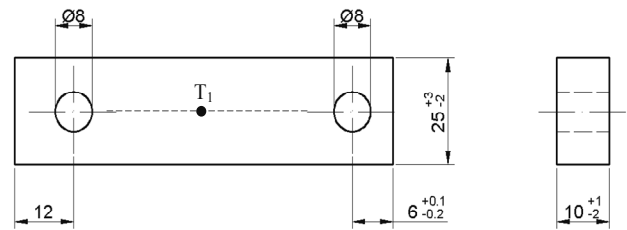

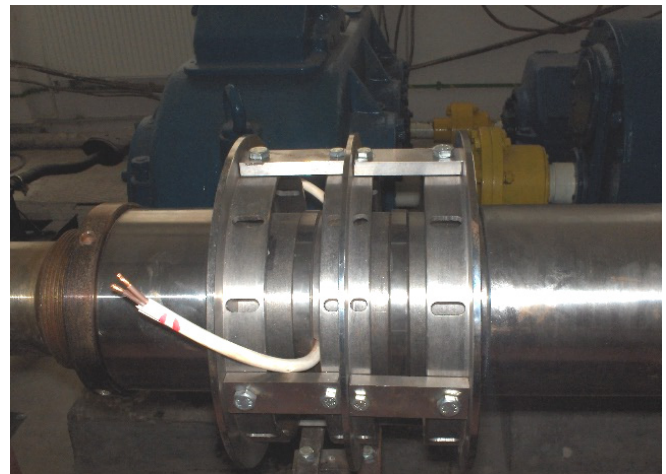Figure 5. Thermocouple positioning
in the experimental sample

Figure 6. Assembly of samples in which a thermocouple is mounted

Electrical conductors from collector brushes of the thermo-tension are connected to a data acquisition system, connected with a computer, and allowing simultaneous determination and recording of temperature variations in the furnace for both type of evidence – inside or outside the furnace; evidence may be cooled in different environments, such as jets of air, water, ice tubes or fire extinguishers. In order to set the temperature of the coolant, we mounted a sample at the bottom of the which encloses a

thermocouple helping it to set up the average temperature at all speeds that will perform experimental tests, figure 7.

In order to take temperature inside and outside the furnace, the thermocouples used has small size and insignificant inertia, figure 8. The aim was to build thermocouples that would not disturb heat flow; so we are using some thermocouple characterized by high thermoelectric power. The wire of 0.5 mm diameter was placed inside the opening made in material δ = 0.8 mm. In figure 9 it is shown a scheme of a thermocouple for the sample temperature measurement.
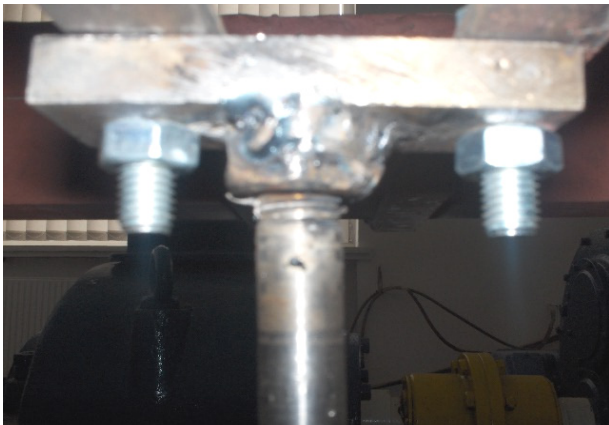

Figure 7. Installation of samples for temperature determination of the cooling environment
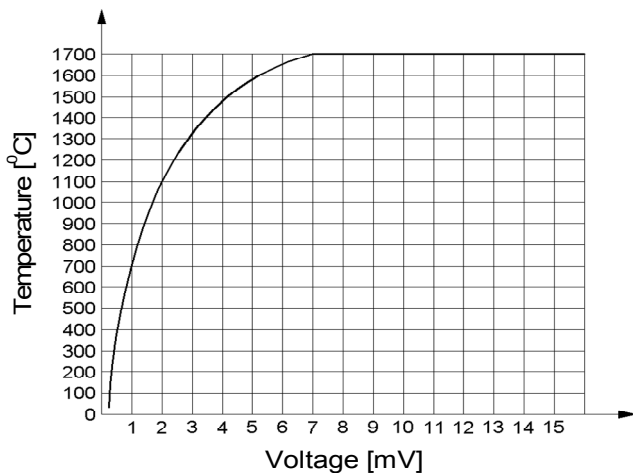

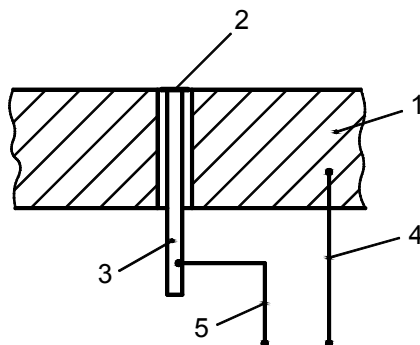*Figure 8. Diagram inertia response of the thermocouples used*

Figure 9. The scheme of a thermocouple for the sample temperature measurement
1- sample; 2- surface of the termocouples, 3- termocouple wire; 4- thermocouple wire connection; 5- sample wire connection

Figure 10 describes the thermo-tensions collector system used in experimental plants, as well as its design scheme with links to data acquisition system. In this figure the main components are:
1 - coupling couple;
2 - copper rings mounted on isolated discs textolit;
3 - carbon brushes;
4 - thermotension colector;
5 - connecting band;
6 - box connections;
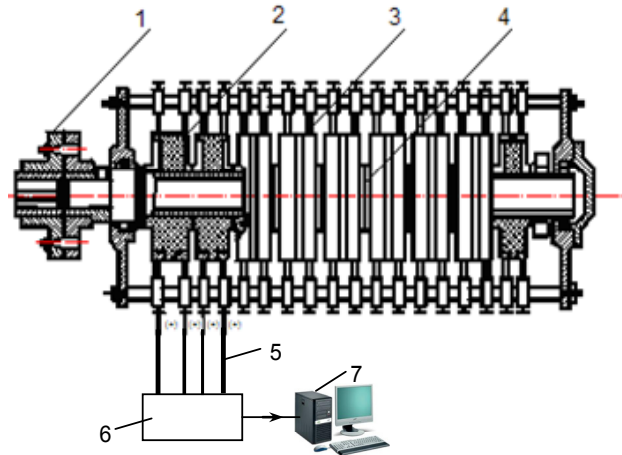*7 - PC desk computer with an acquisition system.*

Figure 10. The design scheme of the thermotension colector with links to data acquisition system

Figure 11. The connection to a data acquisition system

The software enables the system to store the experimental data as databases, from where they are processed and converted into temperature charts, [9]. The level and evolution of the thermal stresses caused by the temperature fields are determined by the diagrams recorded, representing the cyclical variations of the variable temperature fields which appear in the samples [3], [9].

Batch of samples is subjected to regimes of loading, aiming at the emergence of the first thermal fatigue cracks.

In order to reduce the number of load cycles to appear facelift thermal fatigue cracks can be admitted as evidence temperature is as high as possible and rapid cooling and steep.

To do this requires that speed electric motor can be change from minimum 100 rot/min, up to the maximum possible 1450 rot/min, this being achieved by means of a rheostat.

EXPERIMENTAL DETERMINATIONS

Allure of diagram presented in figure 12 confirms the theory found in the literature and thus validate the proposed model and experimental system developed for determining the thermal fatigue test machine in the fixed and mobile parts made of different internal combustion engines composition.

Variations of temperature fields of the samples have been recorded in very small time intervals, which indicate that the system accurately modelling the real situation inside combustion engines.
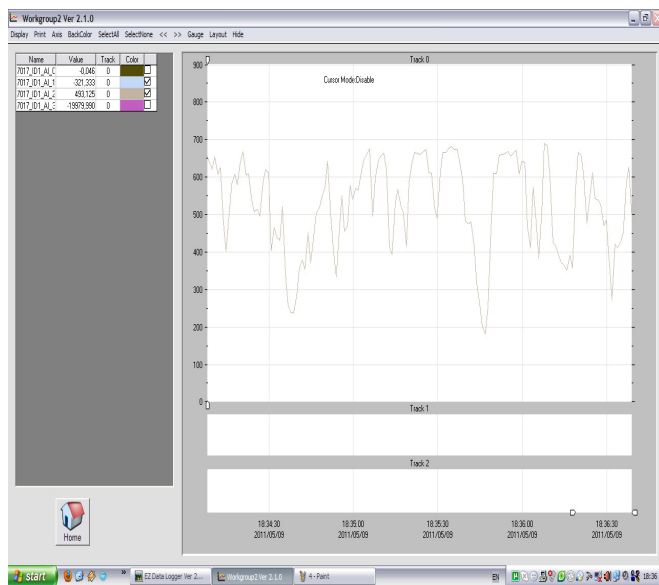

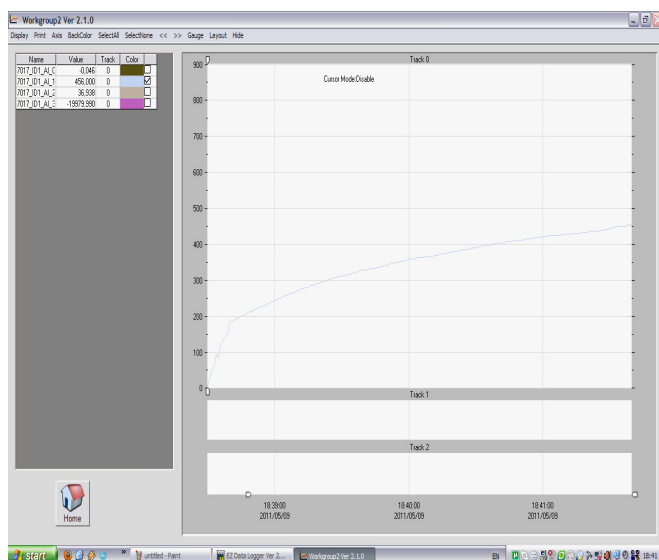Figure 12. Diagram of the temperature field variation in the sample

Figure13. Diagram of the temperature inside the furnace

Figure 13 diagram shows the evolution of the temperature inside the furnace to the start of experimental facility. When starting the system, temperature increases from zero to the value of $900^{0}C$ after which it maintained at this value during the experiments.

In the diagram shows a sequence only includes increasing the temperature up to $450^{0}C$ value.

This model confirms that the proposed experimental plant is well designed and built the wiring, which allows conducting experiments under optimal conditions.

CONCLUSIONS

The experimentally obtained temperature charts confirms the existence of variable temperature fields in the sample mounted in the experimental installation.

The temperature variation chart shows that its rate of change is of the order of seconds, consistent with the engine working cycle. The temperature charts allow the evaluation of the variable temperature fields and the determination of the associated thermal stresses. Their knowledge allows us to make a comparison with those determined by numerical methods, commonly used in the design of the machine parts fitted in the internal combustion engines.

The experimental facility meant to study thermal fatigue was designed and build based on concepts and laboratory modeling methods currently available in the literature and was validated following results.

On the other hand, these experiments are used to study the resistance at thermal fatigue of the component parts of internal combustion engines.

The findings may open the way for creating materials with high resistance to thermal fatigue, allowing the development of high performance parts fitting in the automotive engines.

REFERENCES

[1.] BOTEAN, A., The study of the thermo-mechanical stresses spark ignition engine using modern method of study, Research report, Td2 cod CNCSIS 230, 2005, Bucharest

[2.] COFFIN, L.Jr., Prediction parameters and their application to high temperature low-cycle fatigue, Proceedings of second International Conference Fracture, Brington, London, 1969, pp.43-54

[3.] GARDYNSKI, L. (1995). Investigation of temperature fluctuations of diesel engine piston, Technical University of Lublin, Poland, pp.108-116.

[4.] HALFORD, G., Low cycle thermal fatigue, Edited by Hetnarski R., Elsevier Science Publisher B.V. 1987

[5.] KEREZSI, B.B, KOTOUSOV, A., PRINCE, J.W.H., Experimental apparatus for thermal shock fatigue investigations, International Journal Pressure Vessels and Pipping, 2000

[6.] MILLER, D., PRIEST, R., Material response to thermal-machanical strain cycling. High temperature fatigue- properties and prediction, Elsevier Applied Science, pp. 113-175, 1987

[7.] NITTA, A., KUWABARA, K., Thermal-mechanical faligue failure and life prediction. High temperature creep-fatigue, Elsevier Applied Science, pp. 203-222, 1988

[8.] PINCA, C. JOSAN, A., *Experimental plant for laboratory research of thermal fatigue phenomenon*, WSEAS International Conference, Cambridge, UK, 2012, pp. 73-78.

[9.] PINCA, C. JOSAN, A., *Determination of the variable temperature fields in the cylinder head of a spark ignition engine*, Precedings of the 22nd International DAAAM Symposium, Vol. 22, No.I, Viena, Austria, 2011, pp. 605-606

[10.] SILVA, F.S.,- *Fatigue on engines pistons-a compendium of case studies*, Engineering Failure Analysis 13, Portugal, 2005, pp. 480-492