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THE EXPERIMENTAL RESEARCH OF THE COMBUSTION ENGINE PISTON PIN STRESS

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***Abstract**: The mechanical loading (stress) that appears in the piston-piston pin-connecting rod system shows special features which are the result of the shape of the parts, the type of acting and the distribution and transmitting of forces from this system. This paper aims to present the piston pin ovalization modality which resulted from the experimental research made on a special test stand for the variant when the piston pin is with tightening (fixed piston pin into the connecting rod foot). The complexity of the phenomenology and the specifically constrains from the reality (which it has been tried to be well presented on the model) show the study opportunity of whole conjugate ensemble, and the phenomena could be observed due to a new testing method of spatial movements based on the three dimensional correlation technology (VIC-3D [4]).*

***Keywords:** piston pin, stress analysis, experimental testing methods, roundness*

1. INTRODUCTION

The strategy of experimental research of the appearance of deformations into the combustion engine piston pin aims at a better understanding of the phenomena and at drawing some scientific conclusions. First, it is necessary that the place where the phenomenon occurs to be analyzed and the loading system which is going to occur to be determined. *The spatial and phenomenological system* is represented by *the environment* where the part is mounted, by the *working space*, which could be also named "functional space" and by *the phenomena* which occur within this space. The subassembly parts that the piston pin interacts with and where it is fixed (the *exciting factor*, in this situation, is the combustion pressure) and the connecting rod reacting increase and complete the phenomenological system. The exciting factor and the reacting from the connecting rod cause the future loading. The *mechanical loadings*, which appear as a result of combustion pressure and alternative movements of piston-connecting rod ensemble, are the most important (Figure 1). Another type of stress is the *thermal loading* which appears as a result of combustion temperature. A *chemical stress* could appear as a result of an aggressive environmental action. Because of a low influence of thermal and chemical stress, the experimental research will focus only on mechanical loadings.

2. THEORETICAL BACKGROUND

In addition to the specifications in the previous chapter, the piston pin mechanical loadings also depend on the connection mode between the conjugate parts of the ensemble. As an integrated part of the spatial and phenomenological system (defined above), the type of piston pin connection has a special importance. Figure 2 shows the common connection types for piston pin with the conjugate parts. The differences can be seen very clearly and a remark has to be made: the variant from the figure 2, a) (fixed pin) can not be seen on the vehicles. The types b) (semifloating pin) and c) (full-floating pin) are the most common ones. The advantages and the disadvantages for the last two are explained in specialized papers. The experimental research in this paper refers to figure 2, type b), where the piston pin is mounted with tightening into the connecting rod foot and free into the piston bosses.

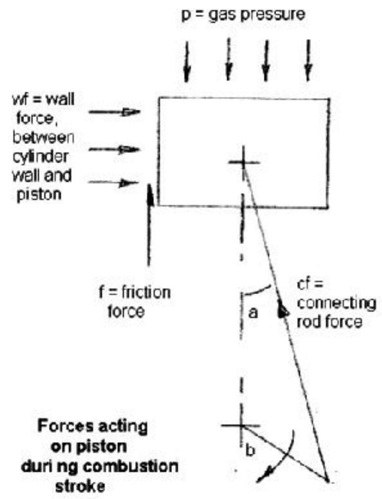
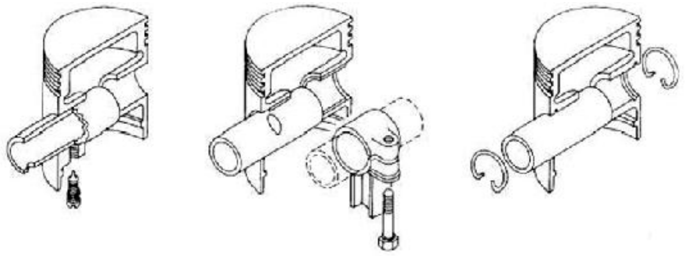


Figure 1: Forces in cylinder unit [1]

The most common types of connection between the connection rod and the piston pin are presented in figure 2. There is some research made in order to change these types of connection with others but manufacturing, assembling, constructive or other types of difficulties restrain the wide implementation.



a) **b)** **c)**

Figure 2: Usually connection types for piston pin in a combustion engine [2]

The possible deformations, which could be met in the situation of piston pin fix mounted into the connecting rod foot, are linked by the two main dimensions. Therefore, longitudinal and in diameter deformation could happen. Because of safe projecting, the longitudinal deformations are very small as absolute values and negligible. We can see the research from [8] which confirms this affirmation. In diameter deformation is bigger and it has to be taken into consideration when the piece will be projected. In figure 3 we can see the piston pin calculation scheme:

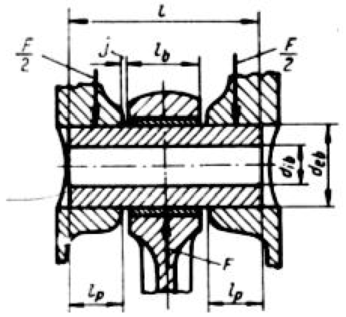


Figure 3: Acting forces and contact areas between piston pin, piston boss and connecting rod [6]

The ovalization calculus formula is:

$$\delta_{d\max} = \frac{0,09F}{lE}\left(\frac{1+\alpha}{1-\alpha}\right)^3 K \tag{1}$$

where:
$K = 1.5-15(\alpha-0.4)^3$
$\alpha = d_{ib}/d_{eb}$

The technical papers presents only one type of piston pin ovalization deformation which does not make the difference between the connection of full-floating pin and the connection of semifloating pin (Fig. 4):

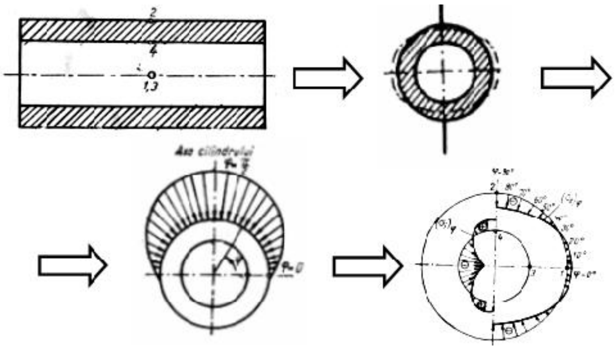


Figure 4: Typical representation of piston pin deformation in literature [7]

It was suggested and demonstrated [8] that the deformations are different in case of the piston pin fixed into the connecting rod foot and the full-floating piston pin. Moreover, the ovalization is different for different sections of the piston pin as it is presented in figures 5 and 6:

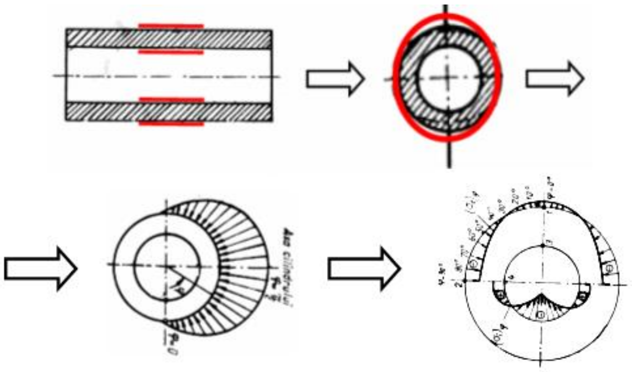


Figure 5: Semifloating pin deformation in the connecting rod small end area [8]

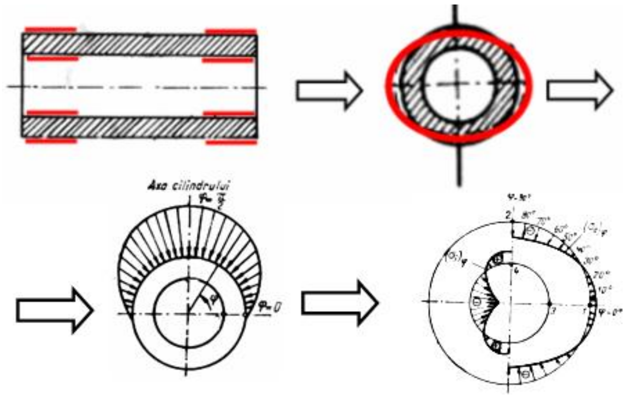


Figure 6: Semifloating pin deformation in the piston boss area [8]

3. MATERIALS

The materials which are used for the piston pin are specially chosen in order to assure the functionality. The piston pin material has to be tenacious and resistant for impact stress. It has a high deformation. The tenacious material has a high deformation and low fracture strength and it has not a proper stiffness to the bending and fatigue stress. The unfinished goods are the rolling ingot. The skin must have high strength (55…65 HRC). This layer must resist to the consumption and fatigue. The tenacity of the pulp must be high (35…44 HRC). The most used materials are plain carbon steel (STAS 880-66) and alloy steel (STAS 791-66), alloying elements Cr, Ni, Mn, Mo, low carbon level (0,12…0,35%). The surface strength can acquire the normal level by using a thermochemical cementation treatment [6], [7]. A piston pin surface covering procedure was adopted by the

MAHLE, named “PVD” (Physical Vapor Deposition). The producer says that this method assures a better piston pin surface covering, it has an improving consumption resistance, decreases the gripping danger in case of inadequate lubrication and it decreases friction. FEDERAL-MOGUL uses a covering method with carbon layers which have features similar to diamond in order to decrease the abrasive wear.

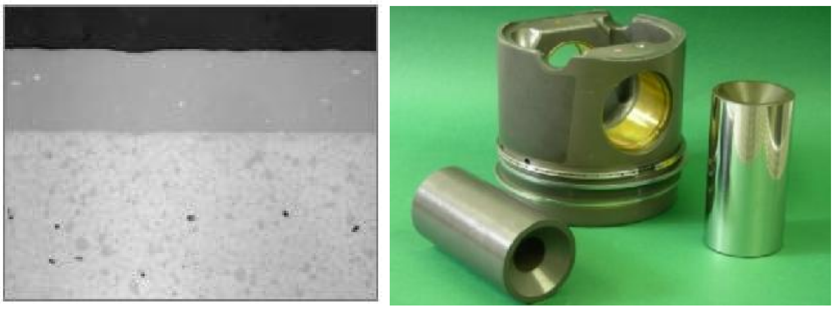


Figure 7: DLC® - coating [9] (left) and Ceramic piston pin for internal combustion engines [10] (right)

The Fraunhofer institute from München, Germany, studies the possibility of using the ceramic components inside of the system piston-piston pin-connecting rod (figure 7). They consider that, besides a semnificative decreasing of load, the energy looses could be decresed due to friction decreasing. The MW Racing, one of the manufacturers of equipments for the engine of rally vehicles, uses titan materials and titan alloyed with aluminium. In figure 8 it can be seen the increasing phenomenon of technological complexity depending on materials performances.

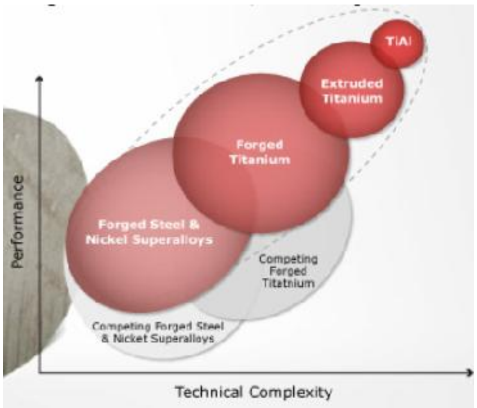


Figure 8: Materials - Performance vs Technical Complexity according to Fa. MW Racing [3]

The American company BME [11] manufacturers a line of Wrist Pins for alcoholburning and nitromethane-burning, supercharged drag race engines. In an 8000-hp, supercharged, nitro-burning engine in a Top Fuel Dragster or a Funny Car, the combustion force is extreme, perhaps around 50 tons. There are very few raw materials with the incredible strength required by wrist pins in a blown-fuel, drag race motor. BME Pins for nitro-burning, supercharged engines are made of VascoMax C-300, an exotic, costly, nickel-cobalt-titanium steel “superalloy” with very high ultimate tensile strength (294,000 psi) and an extreme fatigue endurance limit (one billion cycles at 125,000 psi). Like Bill Miller Engineering’s 9310 VAR Pins, the VascoMax C-300 Wrist Pins receive BME’s special manufacturing processing which gives the O.D.s and I.Ds that distinctive, high-quality, mirror finish.

4. EXPERIMENTAL DETERMINATION

The installation used for experimental testing consists of WPM, type ZDM 2214 pulling/compression machine and a modern optical measurement system “video image correlation” (VIC-3D) which has no contact with the tested ensemble [8]. The aim of the test is to research and to demonstrate the existence of ovalization phenomenon different in semifloating pin. It comes to complete the theory from technical papers. Values of the results can not be seen because it is only one test. There are more tests necessary. The observation areas (blue) and the testing training were shown in figure 9:

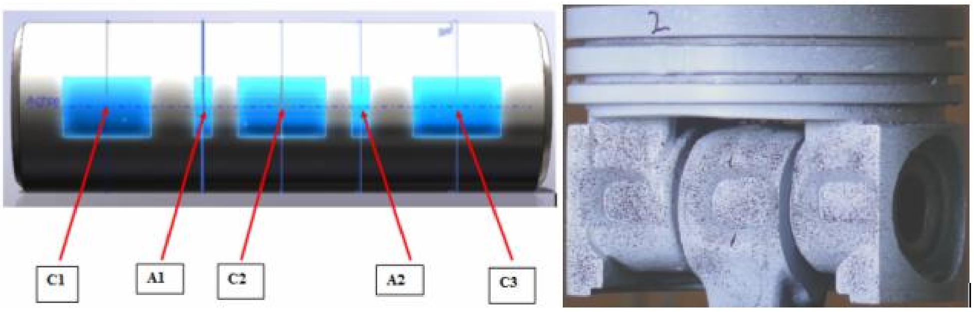


Figure 9: Observation area and preparation of the components (pin, piston, connecting rod) [8]

Example of taking points for the C1, C2, C3 and A1 areas, as they were registered by the program, in figure 10:

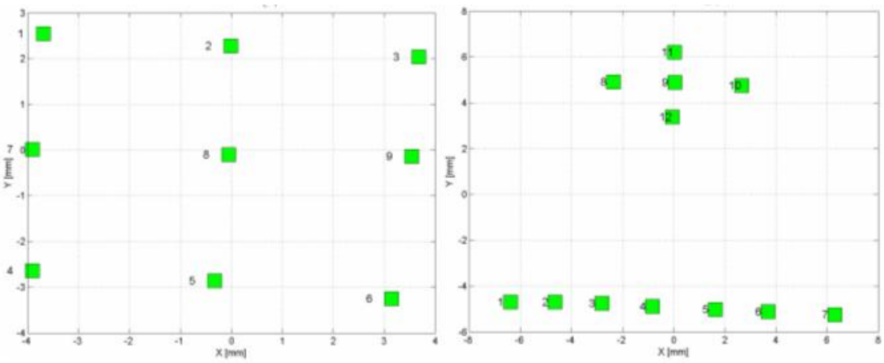


Figure 10: Observation area and preparation of the components (pin, piston, connecting rod) [8]

The results of the experimental tests shown in figure 11 confirm the existence of different ovalization in piston boss area (outside moving – green colour) and in the connecting rod small end area (inside moving – blue colour).

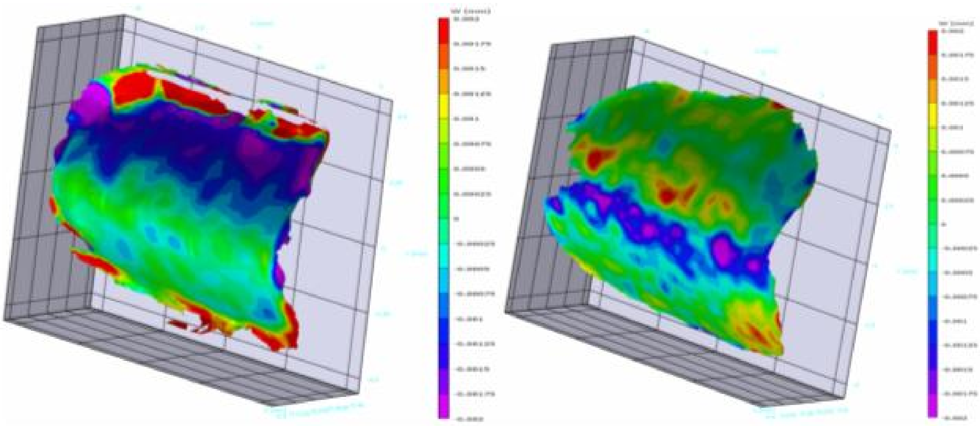


Figure 11: Semifloating pin ovalization in piston boss area (left) and connecting rod small end area (right) [8]

5. CONCLUSION

Taking into account that the applied force on these tests is less, approximately half the real force (≈ 20000 N), the measured displacements are less. The tested piston pin dimensions are:

- 20 mm – the external nominal diameter;
- 13 mm – the internal diameter;
- 62 mm – the length;
- 89,69 g – the weight.

The numerical value of these displacements was different from the value calculated by using classical formula. This one takes into account a high number of cycles of the ensemble. Only one test was made because of financial and logistical reasons, by using half of the value of loading. That is why the final result was different from the theoretical value that was calculated by using the classical formula. The main purpose of the tests was to demonstrate the ovalization phenomenon which is different in contact area with conjugate parts for the situation of piston pin fixed into the connecting rod foot.

The medium ovalization which was experimentally determined into E2-C1-1 (the piston boss) area: (0,0005 … 0,001) [mm] approximately.

The medium ovalization which was experimentally determined into E2-C2-1 (the connecting rod foot) area: (-0,000175 … -0,002) [mm] approximately.

The medium ovalization which was experimentally determined into E2-C3-1 (the piston boss) area: (0,0005 … 0,001) [mm] approximately.

The tests demonstrated the existence of different displacements (ovalization) for the noticed areas. Thus, the initial hypothesis was confirmed. These results of the tests can be used to appreciate the piston pin behaviour mounted tightened into the connecting rod foot and other tests can be done by using more test bar which could offer the possibility to draw up some empiric calculus formulas.

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