SCI-CONF.COM.UA

MODERN PROBLEMS OF SCIENCE, EDUCATION AND SOCIETY

PROCEEDINGS OF IX INTERNATIONAL SCIENTIFIC AND PRACTICAL CONFERENCE
NOVEMBER 6-8, 2023

KYIV
2023

MODERN PROBLEMS OF SCIENCE, EDUCATION AND SOCIETY

Proceedings of IX International Scientific and Practical Conference

Kyiv, Ukraine

6-8 November 2023

Kyiv, Ukraine

2023

UDC 001.1

The 9th International scientific and practical conference “Modern problems of science, education and society” (November 6-8, 2023) SPC “Sci-conf.com.ua”, Kyiv, Ukraine. 2023. 1705 p.

ISBN 978-966-8219-87-0

The recommended citation for this publication is:
Ivanov I. Analysis of the phaunistic composition of Ukraine // Modern problems of science, education and society. Proceedings of the 9th International scientific and practical conference. SPC “Sci-conf.com.ua”. Kyiv, Ukraine. 2023. Pp. 21-27. URL: https://sci-conf.com.ua/ix-mizhnarodna-naukovo-praktichna-konferentsiya-modern-problems-of-science-education-and-society-6-8-11-2023-kiyiv-ukrayina-arhiv/.

Editor
Komarytskyy M.L.
Ph.D. in Economics, Associate Professor

Collection of scientific articles published is the scientific and practical publication, which contains scientific articles of students, graduate students, Candidates and Doctors of Sciences, research workers and practitioners from Europe, Ukraine and from neighbouring countries and beyond. The articles contain the study, reflecting the processes and changes in the structure of modern science. The collection of scientific articles is for students, postgraduate students, doctoral candidates, teachers, researchers, practitioners and people interested in the trends of modern science development.

e-mail: kyiv@sci-conf.com.ua

homepage: ***https://sci-conf.com.ua***

©2023 Scientific Publishing Center “Sci-conf.com.ua” ®
©2023 Authors of the articles

TABLE OF CONTENTS

AGRICULTURAL SCIENCES

VETERINARY SCIENCES

BIOLOGICAL SCIENCES

TECHNICAL SCIENCES

TECHNICAL SCIENCES

УДК 621.431, 621.43.013.7

MODELING OF DAMAGE TO CONROD-PISTON GROUP DURING HYDROLOCK IN INTERNAL COMBUSTION ENGINE CYLINDER

Khrulev Alexander
Ph.D, senior researcher
International Motor Bureau
Ukraine

Annotation. A method has been developed for calculating the connecting rod stem deformation in the process of compressing air with fluid in an internal combustion engine cylinder. A simulation of the compression process is carried out and the dependence of the air pressure in the cylinder, the stress and the deformation of the connecting rod on the filling ratio of the combustion chamber with liquid is found. The results of the calculations are compared with the available experimental data on the deformation of the conrods during a hydrolock and verified using the well-known program for calculating the engine operating cycle, and good accuracy of the developed method has got. As a result of the calculations, it has been found that the conrod deformation with a loss of stem stability occurs with minimal combustion chamber liquid filling ratio of 80%.

Keywords: internal combustion engine, connecting rod, buckling, failure, damage, hydrolock, modeling, liquid filling ratio.

Introduction. From the practice of studying the failure causes of internal combustion engines, it is known that the ingress of liquid into the cylinder is one of the very common causes of severe damage in operation, which causes inoperability (failure) of the engine up to its irreparability. This phenomenon has received a common conventional name - hydrolock [1, 2].

Despite quite numerous references to hydrolock in information sources [3], they usually do not provide quantitative estimates or characteristics of this phenomenon. The description of a hydrolock is often limited to only a brief mention of some of its features, and in most cases it is incomplete. This is not enough to identify all signs of damage and identify the cause of a particular engine failure.

In addition, in known sources there is no data on the influence of the amount of liquid on the magnitude and nature of deformation of parts - primarily the connecting rod buckling. At the same time, known studies of conrod buckling [4] are usually limited only to the deformation itself and do not address in detail the mechanism that causes it.

Aim of the work is the study and modeling of the hydrolock mechanism in an engine cylinder in order to identify the quantitative characteristics of this phenomenon.

To achieve this purpose, including compiling design equations for the model, it is necessary to consider some features of the phenomenon under study. As experience shows [5, 6], when liquid enters the cylinder, the connecting rod turns out to be the "weakest" link in the conrod-piston group and experiences significant axial compressive loads. As a result of which the conrod stem can lose stability (buckling) and deform.

Materials and methods. To determine the deformation value of the stem along the length, an indirect method [7] is sufficient - to measure the height of the carbon deposits in the upper part of the cylinder and compare it with those cylinders where no hydrolock was detected (Fig. 1). It can be assumed that it is proportional to the amount of liquid entering the cylinder. However, it remains unclear how much liquid is needed to cause any given deformation.

The task of determining the deformation of the conrod stem when liquid enters the cylinder can be divided into several stages. At the first stage, it is necessary to consider all the geometric and kinematic parameters associated with the movement of the piston in the cylinder in the presence of liquid. This makes it possible to compile design equations for the parameters of the air in the cylinder. After that, the desired deformation of the conrod stem can be obtained.

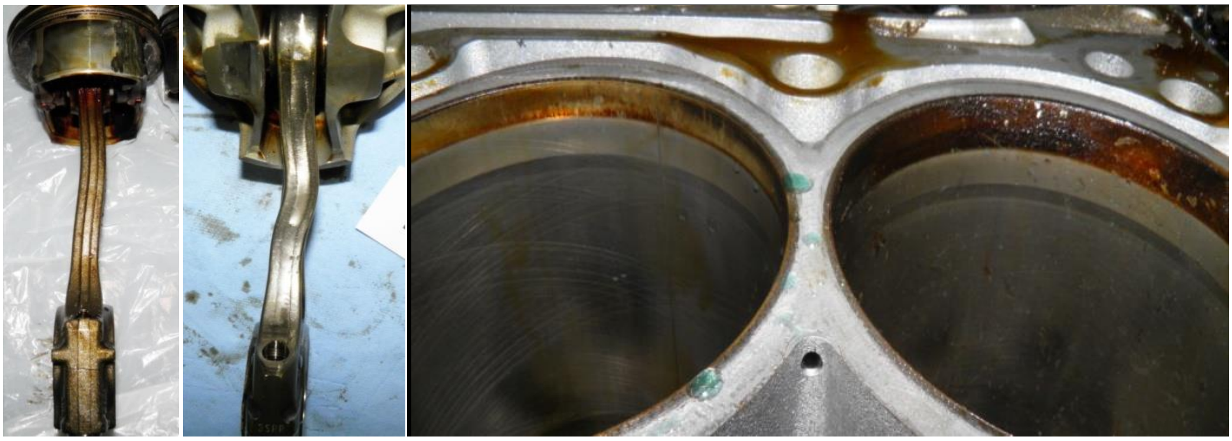

Fig. 1. A typical type of connecting rod stem buckling in the direction of the crankshaft axis during a hydraulic shock in an internal combustion engine cylinder (left) and expansion of the carbon deposits in the upper part of the cylinder when working with a deformed conrod stem after hydrolock (right)

To solve the task, you must first make simplifying assumptions that will allow you to create the appropriate equations, but, at the same time, will not have a noticeable negative impact on the result. In accordance with this, the following simplified assumptions were accepted [8]:

1) the liquid entering the cylinder is incompressible,

2) the physical properties of the liquid are assumed to be unchanged,

3) in the process under study, the liquid does not undergo evaporation,

4) ignition and combustion of fuel are excluded,

5) air leaks from the cylinder are not taken into account,

6) the instantaneous air parameters are the same in volume,

7) the crankshaft rotation speed is constant.

Let us now consider the process of compression of air with liquid in the cylinder from the moment the intake valves close. The geometric compression ratio is:

$$\boldsymbol{\varepsilon} = {}^{\boldsymbol{V_h}}/_{\boldsymbol{V_{kc}}} + \mathbf{1}\,,$$

where $\boldsymbol{V_h} = \boldsymbol{S}\,{}^{\boldsymbol{\pi}}/_{\mathbf{4}}\,\boldsymbol{D^2}$ is working volume of the cylinder, *S* is piston stroke, from where the value of the current air volume in the cylinder will be equal to:

$$\boldsymbol{V} = \boldsymbol{V_h} \left({}^{\boldsymbol{x}}/_{\boldsymbol{S}} + \frac{\boldsymbol{1-\varepsilon_v}}{\boldsymbol{\varepsilon-1}} \right) = \boldsymbol{V_h A_\varphi} . \ (1)$$

where: $\boldsymbol{x}$ is the current coordinate of the piston bottom, measured from the top dead center, *D* is the cylinder diameter, $\boldsymbol{V_{kc}}$ is the volume of the combustion chamber, $\boldsymbol{\varepsilon_v} = {}^{\boldsymbol{V_v}}/_{\boldsymbol{V_{kc}}}$ is the coefficient of filling the combustion chamber with liquid.

According to the 1st law of thermodynamics:

$$\boldsymbol{dU = dA - Q_w\, d\tau} , \ (2)$$

where $\boldsymbol{dA = -pdV}$ is thermodynamic work, $\boldsymbol{Q_w = \alpha_w F_w (T - T_w)}$ is the amount of heat removed from the air into the walls, $\boldsymbol{\alpha_w}$ is coefficient heat transfer, $\boldsymbol{F_w = \pi D\ (0,5\ D + x)}$ is the area of the cylinder walls, $\boldsymbol{dU = mC_p\, dT}$ is change in internal energy during the process, $\boldsymbol{C_p}$ is heat capacity of air, *m* is mass of air in the cylinder (not compressed changes because there is no leakage from the cylinder).

The expression for *dV* can be obtained as:

$$\boldsymbol{dV = V_h\, dA_\varphi = V_h\, B_\varphi\, d\varphi} , \ (3)$$

where coefficient $\boldsymbol{B_\varphi = 0,5(sin\varphi + \lambda_c\, sin2\varphi)}$.

Let us also write down the equation of state relating the pressure *p*, temperature *T* and volume *V* of air in the cylinder:

$$\boldsymbol{p\, V = m\, R\, T}, \ (4)$$

where $\boldsymbol{R}$ the gas constant of air.

After differentiating and transforming equations (2) and (4), we obtain:

$$\begin{cases} {}^{\boldsymbol{dT}}/_{\boldsymbol{d\varphi}} = -\boldsymbol{T\,\gamma\,\psi} \\ {}^{\boldsymbol{dp}}/_{\boldsymbol{d\varphi}} = -\boldsymbol{p\,\gamma\,(\psi + \frac{C_p}{R})} \end{cases}, \ (5)$$

where the coefficients are: $\boldsymbol{\psi = 1 + \frac{30\alpha_w F_w R}{\pi\, n\, p\, V_h\, B_\varphi}(T - T_w)}, \boldsymbol{\gamma = \frac{R\, B_\varphi}{C_p\, A_\varphi}}$.

System of equations (5) can be solved numerically with initial conditions; the solution represents the numerical values of pressure and temperature as a function of the crankshaft rotation angle.

To calculate the initial values of the parameters, the Lotus Engine Simulation program was used [6, 7]. When calculating, the type of internal combustion engine was specified - gasoline one with spark ignition, engine size 83x80 mm, compression ratio 9.0, operating mode 3000 rpm, intake valve closing 40^0 after bottom dead center, wall temperature 390K and other parameters. These data made it possible to calculate the initial values of pressure and temperature corresponding to the moment of closing the intake valves. They are necessary for subsequent modeling of hydrolock by calculating the compression stroke in the presence of liquid (for this example, $\boldsymbol{p_0 = 0,123\ MPa, T_0 = 363K\ at\ \varphi = 220^0}$ were obtained).

The relationship between cylinder pressure and connecting rod stability can now be established. If, for the compression process under consideration, we neglect the inertial forces acting on the connecting rod (which is quite fair if the liquid filling coefficient is noticeably higher than zero and the crankshaft rotation speed is low), then the axial compression force of the connecting rod is determined by the pressure in the cylinder *p* and is equal to:

$$\boldsymbol{R = (p - p_0)F}, \quad (6)$$

where $\boldsymbol{F = {}^{\pi}/_{4}\, D^2}$ is the piston area, $\boldsymbol{p_0}$ is the pressure in the crankcase (to the 1st approximation, it can be equal to the ambient pressure).

The compression force is perceived by the cross section of the conrod stem *A*. Then, obviously, the compression stress in the rod is:

$$\boldsymbol{\sigma = {}^{R}/_{A} = (p - p_0)\, {}^{F}/_{A}}. \quad (7)$$

Calculation of the process of air compression in a cylinder with the above initial conditions in the range of crankshaft rotation angles from the moment the intake valves close ($\boldsymbol{\varphi = 220^0}$) to top dead center was performed for various values of the combustion chamber liquid filling coefficient $\boldsymbol{\varepsilon_v}$.

The specified values $\boldsymbol{\varepsilon_v = 0 - 1,2}$ made it possible to obtain a change in pressure in the cylinder in a wide range of states - from compression of pure air without liquid to compression of air with liquid, the volume of which is 20% greater than the volume of the combustion chamber.

Results and discussion. The calculation results (Fig. 2a) show that the pressure in the cylinder begins to increase noticeably compared to conventional compression without liquid only 50-60^0 before the top dead center, and 10^0 before it, with a large liquid filling coefficient, the pressure can increase by tens or even hundreds of times.

In Fig. 2b presents a diagram of the stresses in the conrod stem, calculated using formula (7). The diagram shows the value of the critical stress $\boldsymbol{\sigma_{cr}}$, above which the area of buckling is located.

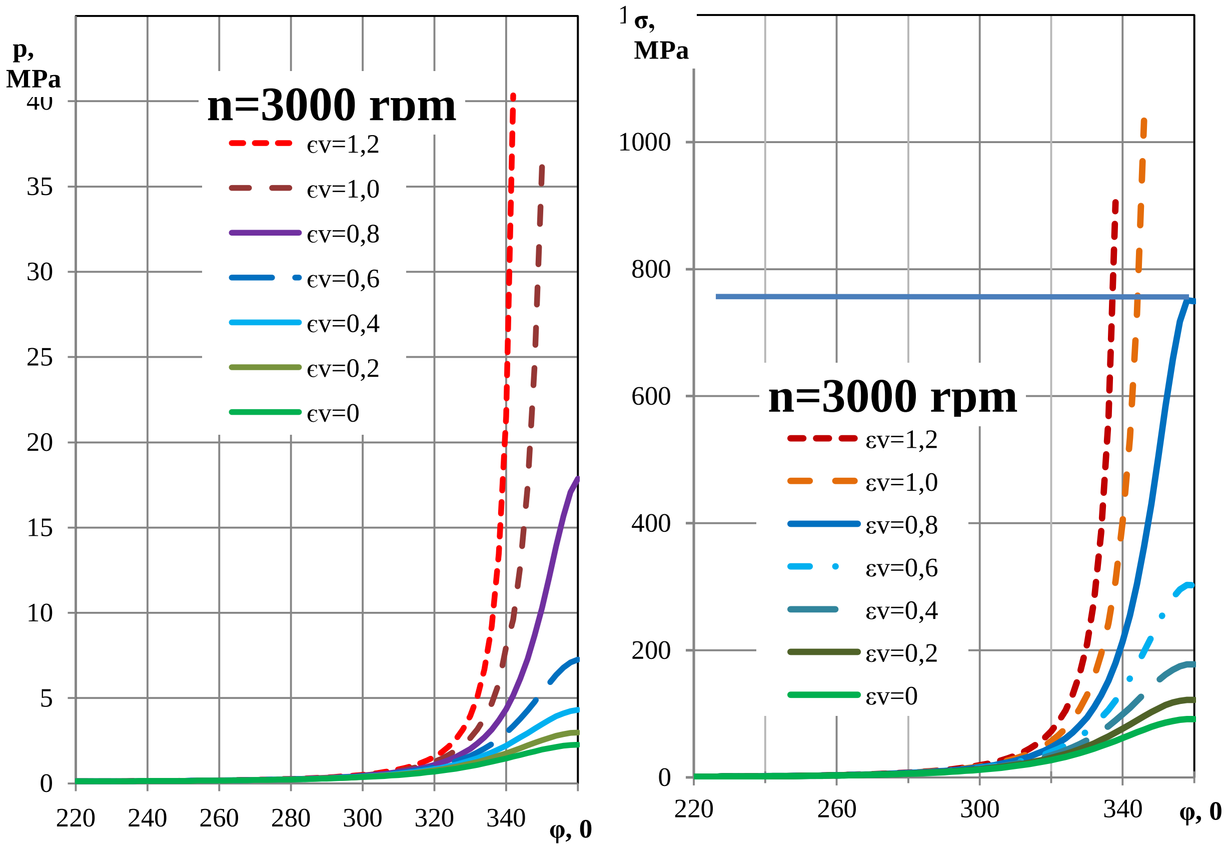

Fig. 2. Changes in pressure in the cylinder (left) and stress in the conrod stem (right) along the crankshaft rotation angle at different values of the chamber filling ratio (the horizontal line shows the stress value above which the area of the conrod stem buckling lies)

The results of calculating the deformation of the conrod stem depending on the combustion chamber liquid filling ratio are presented in Fig. 3. You can see the lines that show areas of small, medium and severe deformation of the conrod stem, above which the engine failure appears (the engine loses workability) due to jamming.

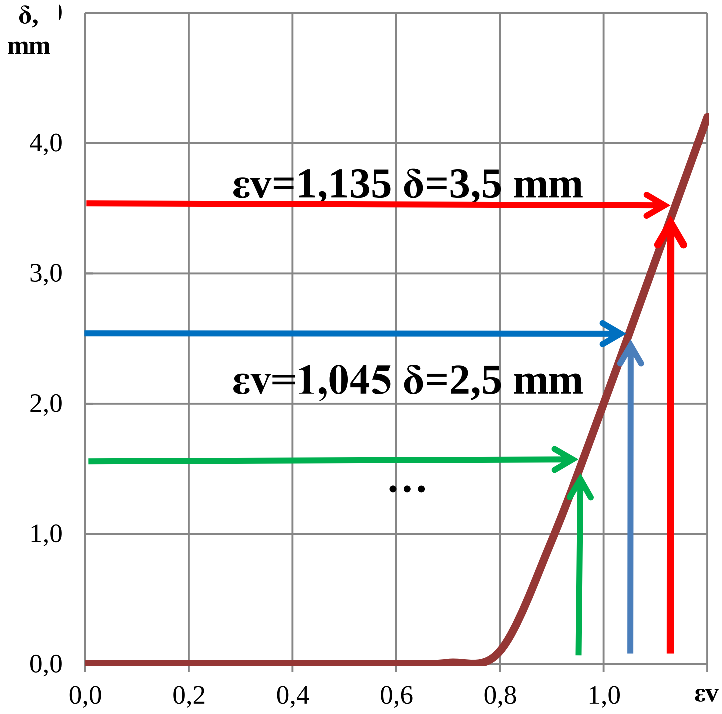

Fig. 3. The amount of deformation (shortening) of the conrod stem during a hydrolock in an internal combustion engine cylinder depending on the combustion chamber liquid filling ratio [8]

Conclusions. From the data obtained it follows that the hydrolock in the internal combustion engine cylinder actually occurs under the condition that the chamber is almost completely filled with liquid, and the onset of plastic deformation of the conrod stem is observed at 80% filling. This means that for the conrod buckling and deformation, a sufficient amount of liquid by volume is only 7-8% of the cylinder volume. The obtained result is important for practice; it refutes assumptions about the possibility of hydrolock only when liquid slowly flows into the cylinder at low rotation speeds, since such a small volume of liquid can enter the cylinders similarly to fuel in droplet form and at high rotation speeds.

REFERENCES:

1. Greuter E., Zima S. Engine Failure Analysis. Internal Combustion Engine Failure and Their Causes. ISBN 978-0-7680-0885-2. SAE International, R-320, Warren-dale, USA, 2012. 582 p.

2. Engine components and filters. Damage profiles, probable causes and prevention. Technical information MS3-1109, Mahle Aftermarket Inc., Farmington Hills, 2009. 76 p.

3. Shenoy P. S. and Fatemi A. Dynamic analysis of loads and stresses in connecting rods. DOI: 10.1243/ 09544062JMES105. J.Mechanical Engineering Science. Proc.IMechE 2006; Vol. 220 Part C, pp. 615-624.

4. Kumar M. and Prajapati S. N. Design, Buckling and Fatigue Failure Analysis of Connecting Rod: A Review. International Journal of Advanced Engineering Research and Science (IJAERS) 2017; Vol.4, Issue 7, pp. 39-44. DOI: https://doi.org/ 10.22161/ijaers.4.7.7.

5. Khrulev A. Internal combustion engines: Fault expertise and analysis. Monograph in 2 vol. V.2. Practical determination of fault causes / A. Khrulev. Chisinau: LAP LAMBERT Academic Publishing, 2023. 562 p. ISBN: 978-620-6-15367-2.

6. Khrulev A., Dmitriev S. The calculating model of air compression process with liquid in the internal combustion engine cylinder. The National Transport University Bulletin: A Scientific and Technical Journal, 2020. Vol.1 (46), pp. 416-426. DOI: 10.33744/2308-6645-2020-1-46-416-426.

7. Khrulev A., Saraev O. Building a mathematical model of the destruction of a connecting rod-piston group in the car engine at hydraulic lock. Eastern-European Journal of Enterprise Technologies, 2022. 3/7 (117), pp. 40–49. DOI: https://doi.org/10.15587/1729-4061.2022.259454.

8. Khrulev A., Dmitriev S. Study of the conrod deformation during piston interaction with liquid in the internal combustion engine cylinder. Journal of Mechanical Engineering and Sciences, 2019. Volume 14. Issue 2, pp. 6557-6569. DOI: https://doi.org/10.15282/jmes.14.2.2020.03.0515.