REVIEW

by Prof. Dr. Eng. Velizara Pencheva
Department of Transport at the University of Ruse "Angel Kanchev"

of a dissertation for the acquisition of an educational and scientific degree "Doctor"

Topic: CHARACTERISTICS OF GAS INJECTORS FOR ENGINES

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Scientific field: 5. Technical sciences
Professional field: 5.1. Mechanical Engineering
PhD Program: Internal Combustion Engines

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1. Applicant information

Stoyan Stoyanov was born on 13.10.1973. He is a full-time PhD student at the Technical University of Varna in the period 2019-2023 and has extensive professional experience in the field of automotive diagnostics, repair and technical inspections of vehicles, accumulated both in academia and in industry. Since 2022, he has been holding the position of assistant professor at the Technical University of Varna, where he conducts exercises and practical training in disciplines related to diagnostics, testing and repair of transport vehicles. The educational path of eng. Stoyan Stoyanov includes completed Bachelor's and Master's degrees in Mechanical Engineering at the Technical University of Varna, as well as participation in specialized programs for automotive vehicles.

2. Actuality of the problem developed in the dissertation in scientific and applied-scientific terms. Degree and scale of the actuality of the problem and the specific tasks developed in the dissertation.

Current trends in the automotive and transport industry are aimed at reducing the negative environmental impact of internal combustion engine cars and increasing their energy efficiency. The increasingly stringent regulatory requirements for emissions of harmful substances in exhaust gases, combined with the need for reliable and economical operation, cause significant scientific and practical interest in the improvement of fuel systems.

The use of gaseous fuels in transport is a promising solution for reducing emissions of carbon dioxide, nitrogen oxides and particulate matter. In this context, gas injectors are a key element of car fueling system, as their operation determines the accuracy of fuel dosing, the formation of the fuel mixture and, ultimately, the environmental behavior of the engine. Deviations in injector parameters can lead to unstable operation, increased fuel consumption and increased content of toxic components in the exhaust gases.

The characteristics of gas injectors are influenced by many factors – design features, hydrodynamic processes in the fuel flow, engine operating modes and working environment conditions. That is why the study of these dependencies has both fundamental and applied importance. On the one hand, it enriches knowledge of the physical processes taking place in combustion equipment, and on the other hand, it supports the development of practical solutions for optimizing injectors and improving the overall efficiency of engines.

The relevance of the topic is underlined by global efforts to develop sustainable transport and by the need to adapt internal combustion engines to new fuels and higher emission control standards. This dissertation is devoted to the study of the characteristics of gas injectors and the influence of hydrodynamic processes on their operation, in order to create prerequisites for more environmentally friendly and economical operation of engines.

3. Knowledge of the state of the problem and creative assessment of the literary material

The list of references includes 117 titles, of which 16 are in Cyrillic and 101 are in Latin.

The dissertation shows an in-depth knowledge of the current state of the problem related to gas injectors and fuel supply systems for liquefied petroleum gas. The literature review examines both the principal features of gas systems and their compatibility with existing engines, as well as the specifics of gas injectors as the main actuator. A clear analysis of the various design solutions is presented, taking into account their advantages and limitations.

The author does not limit himself to a descriptive review, but critically evaluates existing methods for determining the characteristics of injectors. Attention is drawn to the applicability and limitations of standardised approaches (ISO 6358, JIS B 8390), including the use of air instead of LPG as the working fluid, discrepancies in operating pressures and differences between static pneumatic tests and the dynamic operation of gas injectors. It is pointed out that this leads to the need for correction of the methodologies and mathematical processing of the data for an adequate assessment of the actual operational characteristics.

The dissertation also uses modern research, in which indirect methods and advanced measurement approaches are applied, and compares them with data from manufacturers and standards. This analytical and comparative work testifies to a creative approach in the evaluation of the literature material, clearly highlighting the unsolved problems and the need to improve the methods for studying gas injectors in real conditions.

It can be argued that the PhD student not only knows the state of the problem, but also performs a critical and creative analysis of the available literature, outlining the gaps in knowledge and formulating a reasoned basis for his own research.

4. Compliance of the research methodology with the set goal and objectives of the dissertation.

The chosen methodology is adequate and fully corresponds to the purpose and objectives of the dissertation. The designed and built specialized stand creates an opportunity to conduct experimental research in conditions as close as possible to the actual operation of gas injectors. This is key to achieving the main goal of determining the actual flow characteristics and identifying the factors affecting fuel delivery.

The methodology includes:

- Design and construction of a bench that reproduces the operating parameters (pressure, temperature, physical state of the fuel), using standard certified components and additional safety and control systems. This fulfills the first task.

- Developed measurement procedures with high-frequency registration of rapidly changing values (current, voltage, pressures, temperature, needle displacement, vibration acceleration), which allow both quantitative and qualitative analysis of the processes – corresponds to the second and fourth tasks.

- mathematical modeling and the ability to compare the theoretically determined flow characteristics with the experimentally obtained results – covers the third task.

- Measurement of the cycle portion of fuel under realistic conditions, which guarantees the reliability of the data and compliance with the operating modes - the fifth task.

- In addition to the technical comprehensiveness, the methodology is also provided with a safety system (gas detectors, automatic valves, operating procedures), which makes the study practically applicable and reliable.

The chosen methodology not only allows achieving the main goal – determining the actual flow characteristics of gas injectors – but also provides rich information about the influence of various factors on their work, which is a significant contribution to the dissertation.

5. Brief analytical characteristics of the nature and assessment of the reliability of the material on which the contributions of the dissertation are built

The dissertation is developed in a volume of 167 pages, formatted in 4 chapters with an introduction, general conclusions, conclusions, scientific and applied contributions and a list of references.

The introduction clearly outlines the relevance of the study, emphasizing the need for modern cars to meet road and environmental requirements. It is stated that the main source of emissions is engine performance and that the reduction of toxic components is achieved through fuel supply management, catalytic neutralization and the use of alternative fuels. Particular attention is paid to gaseous fuels (CNG and LPG), which provide lower carbon emissions and the amount of limited components in the exhaust gases.

The introduction justifies the focus of the dissertation on gas injectors as a key element of combustion equipment, whose characteristics and hydrodynamic processes affect the dosing precision and environmental behavior of the engine. The presentation lays the foundations for the purpose and tasks of the research, arguing the scientific and practical significance of the research.

Chapter I examines modern liquefied petroleum gas (LPG) fuel systems in internal combustion engines, focusing on the principle of operation of electronically controlled gas systems and the role of gas injectors as the main actuator. The different design types of gas injectors and their influence on the precision of fuel dosing are presented. Chapter I provides a detailed overview of existing methods for determining the flow characteristics of gas injectors, including the ISO 6358 standard and indirect methods, discussing their limitations – use of air instead of real fuel, different pressures, operating dynamics and technological measurement times. The conclusions highlight the need to adapt the methodology for accurate and reliable results in real operating conditions. The main emphasis of the chapter is on the scientific substantiation of the importance of gas injectors for the efficiency and environmental friendliness of the engine and the need to develop experimental and mathematical methodologies to determine their actual characteristics.

Chapter II, the dissertation presents a correct numerical modeling of gas-dynamic processes in an injector using SolidWorks FlowSimulation, building a 3D model, defining boundary conditions, and analyzing the influence of basic parameters on mass flow. The approach is appropriate and the results are well illustrated. The presented dependencies are logical and consistent with theoretical models, but could be supplemented with a more in-depth quantitative analysis and a clearer outline of the contribution to injector optimization.

Chapter III is dedicated to the construction of a specialized bench for studying the characteristics of gas injectors and the development of a methodology for processing experimental data. A laboratory system is presented in detail, which allows the management and control of the main parameters determining the operation of the injector, such as pressure, temperature and flow conditions. The supply and outlet tanks, the reducer-evaporator, the heating system, the vacuum pump and the compressor, as well as the additional safety and adjustment components, are described. Special attention is paid to security measures when working with liquefied petroleum gas, including the certification of the elements, the vacuuming of the system, the implemented detection of gas leaks and emergency protections.

In addition, the control panel on the bench is presented, which facilitates the management of experiments and the visualization of the measured parameters. A methodology for recording and systematizing experimental data has also been developed, including logging of conditions, registration of measured quantities and use of a system for acquisition of dynamic processes. Thus, the chapter justifies the reliability of the experimental base, which serves to validate numerical models and to investigate the influence of various factors on the characteristics of gas injectors.

In the experimental part in Chapter 4, the dynamics of the needle of a gas injector under various electrical, thermal and hydraulic conditions are studied. The main factors influencing the magnitude of the mass flow rate of the fuel passing through the injector have been determined. Low-impedance injectors have been found to show increased sensitivity in terms of supply voltage. A new criterion for evaluating the injector opening period has been formulated, based on the requirement for

repeatability of mass flow results. The fuel cycle portion and leakage ratio depend on the throttle diameter, pulse duration, pressure and temperature, and the results are consistent with theoretical and numerical models. The experimental results highlight the significant influence of electrical parameters, temperature, pressure and geometry on the dynamics and efficiency of the gas injector.

6. Scientific and applied contributions of the dissertation

In the dissertation, effective methods, tools and approaches of direct practical importance have been developed and applied. The results obtained and the conclusions drawn contain contributions that can be divided into two main groups – scientific and applied contributions

Scientific-applied contributions

1. A hydrodynamic model of a gas injector has been created, showing the nonlinear influence of the nozzle diameter on the throughput, and at larger diameters there is a redistribution of pressure drops between the valve area and the nozzle opening

2.The leakage coefficient values for different diameters of the throttle have been determined, establishing a decreasing trend with increasing diameter due to the changing ratio between the structural resistance and the orifice.

3. Dependencies for the time-sections at different duration of the control pulse are derived, and their linear increase of more than 5 ms and the relationship with the resistance of the winding are proved.

4.The influence of various factors such as injector temperature, different coil resistance value, differential pressure and throttle diameter has been studied. It has been found that sustained results for flow characteristics are obtained after injector tempering and a minimum electrical pulse duration exceeding the injector opening time

5.The influence of oscillatory processes on the pressure values in the fuel leakage zone has been determined and it has been established that with longer duration of the control pulse and engine crankshaft rotation frequencies, the injector opens under conditions of undamped pressure fluctuations.

Scientific and applied contributions can be divided into groups: proving by new means essential new sides in existing scientific problems.

Applied contributions

1. A specialized bench has been designed and built to study the flow characteristics and dynamics of gas injectors, accompanied by operating methodologies and safety instructions.

2. The developed methodology and bench are applicable for calibration and optimization of fuel supply systems in engines with alternative fuels.

3.The results obtained have the potential for environmentally friendly applications through more precise control of the fueling process and reduction of toxic emissions.

4. The stand and the methodologies developed can be used for training and qualification of specialists in the field of gas injection systems.

Applied contributions can be divided into groups: obtaining and proving new facts and obtaining confirmatory facts.

7. Assessment of the extent to which the dissertation work and contributions are a personal matter of the PhD student

On the basis of the presented dissertation and the published scientific works, it can be estimated that the dissertation work and the achieved scientific-applied and applied contributions are a personal work of the PhD student Eng. Stoyan Nedelchev Stoyanov. The work in the dissertation shows his independence in research, stable theoretical knowledge, as well as competence in analysis and experimental activity, while being carried out under the scientific guidance of his supervisors and with the support of colleagues from the department.

8. Assessment of the publications of the dissertation.

The PhD student has presented a list of four publications, one of which is independent, published in the materials of the Scientific and Technical Conference with International Participation EKO Varna, 2023. two of them have been published in peer-reviewed journals, indexed in Scopus, and presented at the XI Scientific Conference with International Participation in Aviation, Automotive and Railway Engineering and Technologies "BulTrans-2019" (10–12 September 2019, Sozopol, Bulgaria) and at the International Scientific Conference "Engineering, Technology and Education" (ICTTE 2020, 4–6 November 2020, Yambol). In one of the co-authored publications mag. eng. Stoyan Stoyanov is the first author.

The publications are contemporary, relevant to the topic of the dissertation, and reflect both the main theoretical and applied results. They support the relevance of the research by showing that the candidate has mastered experimental methods, data analysis and scientific communication in an international and national environment.

9. Use of the results of the dissertation in scientific and social practice.

The results of the dissertation are already being applied in scientific practice through publications in peer-reviewed journals and presented at international conferences. They can also be used in social and industrial practice, especially in the field of design, research and optimization of gas injectors, as well as in the preparation of training materials for engineers and specialists in the automotive industry.

10. Recommendations for future use of scientific and applied-scientific contributions.

The scientific and applied-scientific contributions can be used to optimize the design and control of gas injectors, to develop new testing and calibration methodologies, to improve digital and hydrodynamic models in education and research, as well as for implementation in industrial applications to improve the dosing accuracy, efficiency and reliability of fuel systems.

11. Abstract

The presented abstract is compiled according to the requirements, its content corresponds to the dissertation and correctly reflects all its main parts. The abstract: clearly presents the topic and subject of the study – gas injectors, their dynamics and flow characteristics; reflects scientific and applied-scientific contributions, including modelling, experimental research and identification of key characteristics (leakage rate, influence of factors); highlights the experimental part, which is central to the dissertation; points out the scientific publications that support the results and authorship of the dissertation; notes the practical applicability of the results.

Only for maximum compliance with the requirements can it be refined stylistically and it is guaranteed that the abstract is a standalone document that allows the reader to understand the contribution and results without referring to the full dissertation. Its volume is 38 pages.

12. Critical notes on the dissertation, including on the candidate's literary awareness

1.Some aspects of the presentation of the results of the study could be further expanded or more clearly formulated, mainly in order to increase the formal precision and completeness of the methodological description.

2. Some of the conclusions from the conducted studies can be refined.

CONCLUSION

The notes on the dissertation are of a recommendatory nature and do not affect the essence of the scientific results achieved, nor the overall positive assessment of the research, which fully meets the requirements for a dissertation.

The work submitted for review, as well as the significance of the PhD student's publications on the topic, give me reason to believe that the educational and research part of the dissertation has

dissertation has been completed. Based on the results and contributions presented in the dissertation, I believe that it meets the requirements of the Academic Staff Development Act, the regulations for its implementation and the rules of the Technical University of Varna.

All of the above gives me grounds to give a positive assessment of the work of Master Eng. Stoyan Nedelchev Stoyanov and to propose that he be awarded a PhD degree, PhD program "Internal Combustion Engines", professional field 5.1. Mechanical Engineering, in the field of higher education 5. Technical Sciences.

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Ruse

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