UNIVERSITY OF MISKOLC
FACULTY OF MECHANICAL ENGINEERING AND INFORMATION TECHNOLOGY

EXAMINATION OF AN ALTERNATIVE SOLUTION FOR THE VALVE SYSTEM OF FOUR-STROKE ENGINES

Thesis booklet

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Certified automotive engineer
Chartered engineer-teacher

SÁLYI ISTVÁN DOCTORAL SCHOOL OF MECHANICAL ENGINEERING
BASIC MECHANICAL ENGINEERING SPECIALITY
TRANSPORT PROCESSES AND THEIR MACHINERY THEME GROUP

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SUBJECT AREA LEADER:
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1. INTRODUCTION

1.1. General considerations

Since the advent of the internal combustion engine, a number of gas exchange control methods have been tested. Of these, the poppet valve has been the most widely used. Its most important feature is that it seals the space to be sealed in such a way that the force compressing the sealing surfaces is proportional to the pressure in the space to be sealed. In other words, the higher the pressure of the combustion chamber, the better the sealing effect within certain limits. In order to achieve this proportionality between the pressure of the space to be sealed and the sealing force, the valve must be positioned in the gas exchange conduit in such a way that the valve head practically blocks the path of the medium to be sealed. However, this arrangement also results in the valve head partially closing the gas exchange passage even when it is not needed at all. In the case of an internal combustion engine, the valve head therefore worsens the flow conditions during intake and exhaust strokes by partially blocking the intake and exhaust ports (Figure **Hiba! A hivatkozási forrás nem található.**).

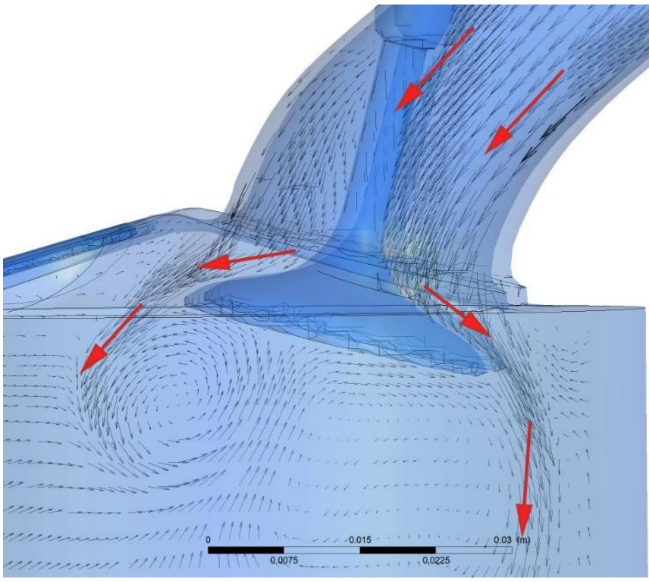

Figure 1: Flow deflecting behaviour of the valve head

At the same time, the movement of the valve spring/valve/cam assembly limits the speed at which the power source can operate and the characteristics of the valve opening [1]. The latter limits the degree of engine charging, and the two together limit the power level attainable [2]. The above-mentioned constraints are a major obstacle in the process of *engine* downsizing[S1] , [3]. Of course, as is described in [2] the problem can be solved by using additional structures such as a turbocharger, but this leads to a more complex structure and higher costs

1.2. Objectives

To overcome the limitations outlined in the introduction, I have developed a swinging ing valve design. The essence of this structure is that it overcomes the shortages of both the poppet valve [4] and the rotary valve solutions. The common problem with both rotary and poppet valves is that during the gas exchange process, the gases entering and leaving the cylinder space are forced to change direction abruptly. In the case of poppet valves, the flow has to bypass the valve head, whereas in rotary valve designs, the edges of the valve body, which move continuously, prevent a loss-free flow [5], [6], [7], [8], [9], [10], [11], [12], [13]. Unlike the rotary valve designs already implemented, swinging ing valves do not perform a continuous rotary motion (Figure **Hiba! A hivatkozási forrás nem található.**), but open or close the intake and exhaust ports by swaying appr. 90^o back and forth. This option can significantly improve the charging efficiency of the internal combustion engine and reduce the amount of work invested during the exhaust stroke, which could otherwise be used to propel the vehicle.

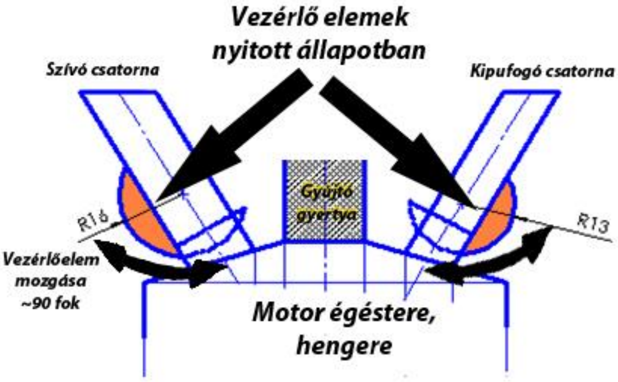

Figure 2: Schematic design of a swinging ing valve system

Due to the low inertia of the swinging valve, the power dissipated by the valve movement can also be reduced. As indicated in the [1] literature, the power consumed by valve actuation accounts for nearly 18% of the total friction loss.

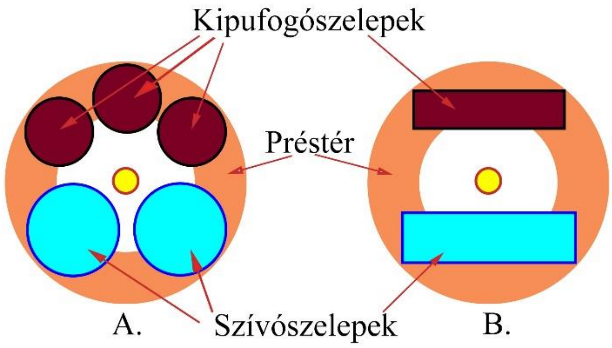

Figure 3: Comparison of the size of the squish area in the cylinder head of the engine with a poppet valve (A) and the engine with a swinging valve (B) (the yellow circle indicates the spark plug).

From a thermodynamic point of view, the design of the combustion chamber of a poppet valve engine is a compromise between geometry that results a more efficient combustion process and valve size that provides adequate gas exchange process. To achieve the highest possible power density, a four-valve valve-layout was found to be the most suitable, but the surface area occupied by the valve heads reduces the surface area of the squish that can be created at the periphery of the combustion chamber. The five-valve system used by Yamaha and Audi is the clearest, albeit extreme, example of this reduction (Figure **Hiba! A hivatkozási forrás nem található.**). A larger squish improves the efficiency of the combustion process, reducing the risk of detonation, as larger percentage of the charge is burnt at the smallest combustion chamber volume.

The advantage of the *squish* effect is that the creation of an intense gas movement occurs immediately before the fresh mixture is ignited.

The use of *swirl* and *tumble* systems can give good results, but the flow required to create a swirl space can only be achieved by designing the intake port in the right shape, which usually reduces the filling efficiency of the cylinder [14], [15], [16]. By using a swinging valve, the size of the squish area is obviously not limited by the size of the valve heads, and the channel design can be chosen more freely to create the desired swirl and tumble effect.

With a swinging valve, there is also no fear of spontaneous combustion caused by a hot exhaust valve head. As a more intense squish effect can be developed, the risk of detonation combustion is also reduced and combustion efficiency is improved. These two conditions allow a higher compression ratio to be achieved compared with a poppet valve engine, using fuel with the same octane rating, which improves the efficiency of the engine and reduces its specific fuel consumption. InTable summarised the advantages that can be expected and achieved by using a swinging valve compared to a power source with a poppet valve.

Table 1: Advantageous operating parameters obtained by using a swinging valve

Benefits of the different valve system design that do not require specific justification	**Expected co-benefits**	**Advantageous features to be examined in the thesis**
A larger squish area can be created	A better power-to-weight ratio is achieved	Better cylinder filling
Due to the lack of a hot exhaust valve head, a higher compression ratio can be applied	With electronic valve control, Miller and Atkinson operating processes can be implemented in different operating conditions.	Reduced flow losses around the intake and exhaust valve
No valve pockets on the piston head, allowing the creation of a combustion chamber that makes the combustion process more efficient	Maximum engine speed can be higher even with large valves	A swinging valve allows more effective control of the tumble of the fresh charge
Larger port cross-sections can be used for the same cylinder dimensions	More efficient combustion can reduce harmful emissions	More perfect cylinder purging is achieved
Exhaust valve opening force requirement independent of combustion chamber pressure		A more perfect and controllable stratified charging process can be achieved
The higher surface area of the squish space makes the combustion process more efficient		

With the swinging valve gas exchange control to be tested in the present work, due to its design, an engine can be expected to achieve a much better filling ratio and a much higher speed without the need for added external systems. Improvement of these two parameters will increase the power density of the engine, which is a key objective of the overall engine downsizing effort.

2. DESCRIPTION OF THE RESEARCH PROGRAMME

In my research, I sought to answer the following questions:

- Examine how the power and torque output compares to engines with conventional valve systems.
- To what extent can the new valve system be integrated into the implementation of the "*Engine Downsizing Concept"*.
- Demonstrate whether the design is applicable to stratified charging operation.
- Justify whether it can be substituted for a more costly, more complex performance-enhancing solution (e.g. turbocharging).

3. WORKING METHODS

In order to be able to determine the properties of the swinging valve system with the necessary accuracy and to compare it with the conventional valve system, the research tasks were organized as follows:

- The primary aim of the literature review was to understand the theoretical background of the experimental research and to formulate detailed objectives. To this end, I first studied the properties and possible applications of already implemented non-conventional valve and control systems.
- I then determined the parameters of the power source that the development work was based, therefore I could compare the results of my research to real life data.
- After defining the parameters, I mapped the control and flow characteristics of the original cylinder head with the poppet valve. The value of the coefficient of flow at each valve lift points was determined during the study.
- In order to make the swinging valve concept directly comparable with a poppet valve and to make the comparison sufficiently accurate, I used the original poppet valve system as the basis for the swinging valve cylinder head to be designed. Therefore, I created a CAD model of the original cylinder head.
- I have created a 0D/1D engine model of the original engine configuration, that was validated against the results of previous dynamometer tests.
- By modifying the CAD model of the originally created poppet valve cylinder head as little as possible, I created a CAD model of the swinging valve cylinder head. Based on the results of the previous research phase, I determined the dimensions of the swinging valves and, based on the CAD model of the poppet valve cylinder head, a swinging valve cylinder head was manufactured.
- Next, it was possible to test whether the swinging valve provides a more efficient gas exchange at the same port cross-section? The assembled cylinder head with a swinging valve was flow tested. The results of the flow experiments were used later in the computer engine model.
- Using the results of the previous research phases, I created a 0D/1D engine model of the swinging valve system. The results of the engine model were compared with the validated and simulated parameters of the poppet valve cylinder head engine.
- I created static and dynamic CFD models of both valve systems. The data obtained from the numerical models was subjected to a comparative analysis in relation to the two valve systems.

- The models created as a result of the tests reproduce the parameters of the real operation with high accuracy and provided an opportunity to test the control system with a swinging valve on a quasi-operating engine, so the research tasks were accomplished by a comparative analysis and evaluation of the results.

4. NEW SCIENTIFIC FINDINGS-THESES

T1. Based on the analysis of conventional poppet valves and literature data, I developed a novel swinging valve cylinder head. Through measurements and simulations, I have demonstrated that the gas exchange characteristics achievable with poppet and other rotary valve solutions are significantly improved by the new design, which minimizes the amount of directional change caused by the valve body on the gas flow into and out of the combustion chamber when the valve is fully open. [S1] [S2] [S5]

T2. I have developed a complex measurement and modelling procedure to create high accuracy computer models of the engine. The measurement and modelling take into account the flow conditions of the internal combustion engine, the kinematics and dynamics of the valve system, thus achieving a representation of the engine parameters of the power source with an accuracy equal to or better than the data reported in the literature. [S3] [S4] [S6] [S7] [S8]

T3. A comparative analysis using the developed complex test procedure has shown that an arrangement in which the intake and exhaust ports are controlled by a swinging valve provides 34.07% and 21.5% better flow conditions during the gas exchange process for the intake and exhaust systems, respectively. Using a validated 0D/1D engine model from my further investigations, I found that a power source using swinging valves can achieve 59% better cylinder filling, while torque increases by 15% and power increases by 32%, compared to an engine with a poppet valve of the same swept volume, which is the basis of the comparison. The results show that an engine with a swinging valve system can achieve a much higher power density than an engine with the same capacity but with a poppet valve. [S2] [S3] [S4] [S7]

T4. As a result of CFD modelling, I have verified that the flow structures are quite different for the two valves under investigation. By combining the flow vectors with the representation of the charge particles in unidirectional motion, the rotating gas masses in the cylinder space clearly represent that a less turbulent, ordered vortex system is formed at the end of the intake stroke with the swinging valve system. I have demonstrated that the vortex structures created during intake phase are more favourable for stratified engine operation without the use of vortex inducing auxiliaries. [S8], [S10]

Testing an alternative solution for the valve system of four-stroke engines

T5. Based on the analysis of the flow data, I found that the Relative Tumble Ratio (RTR) of the fluid motion in the vortices was 13.1 times better for the swinging valve system, which creates highly favourable operating conditions for an engine using the Otto principle with a stratified charging process. [S9], [S10]

5. LIST OF PUBLICATIONS RELATED TO THE RESEARCH AREA

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