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BEHAVIOUR OF DIFFERENT TYPES OF CHECK VALVES USED IN HYDRAULIC SYSTEMS

BY

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Abstract. From the complex systems used in the manufacturing plants to the safety and comfort systems from a vehicle, hydraulic systems are indispensable in most industries. A wide variety of valves assures the functionality of the hydraulic systems, and each valve has a specific purpose. The most used and simplest valves are check valves designed to allow flow in one direction and to prevent flow from the opposite direction. Check valves may have different designs depending on the application and where they are used. A trouble-free functionality of the hydraulic system is given by the proper selection of the check valves. The paper is providing an overview of the research conducted on the most common check valves and their behaviour in hydraulic systems like the relationship between Reynolds number and the drag coefficient of a ball in a fluid, and boundary layer separation for laminar and turbulent flow. The optimum operation of the hydraulic systems is ensured by a multitude of check valves where research and development must continue to provide better future solutions.

Keywords: check valve; valve slam; laminar flow; turbulent flow; boundary layer.

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1. Introduction

Nowadays, every hydraulic system has at least one check valve without which it could not function properly. Check valves have the purpose of allowing fluid flow in one direction, and of blocking the fluid flow from the opposite direction (EL-Zahaby *et al.*, 2015). These types of valves are mainly used in those hydraulic systems where a reverse flow is not allowed to keep the flow or pressure in the system at a predetermined value.

Check valve designs may differ from application to application. In a pumping station are needed large valves which can pass through a high fluid flow, while in the automotive sector in the hydraulic system of the vehicle the valves must be small and operate very quickly.

A proper selection of check valves is critical for a good performance of the entire hydraulic system. Even if all check valves have the same purpose, some of them might not be appropriate to the system and during functionality leads to operability problems, premature wear, vibration and noise. The criteria for selection of a check valve to be installed on a hydraulic system must be evaluated based on factors as the size, the length of the pipeline, the fluid that will be used, temperature of the fluid, the minimum and maximum operable flow rate, the minimum and maximum operable pressure, head loss characteristics, the operating and maintenance costs and controllability (Val-Matic, 2018; Flowserve, 2010). The biggest concern for engineers about the selection of check valves is whether the valves slam or not in various systems. Considering these, in our paper it is presented a test methodology to observe check valves performances.

Most of the valves used in automotive systems are spring-loaded valves because they are cheap, easy to produce and have good performances. Depending on the design and the system where the spring-loaded ball check valves are installed, the valves may generate a disturbing noise. Due to a high-velocity fluid flow passing over the ball and operating in a high-pressure system, the ball may become unstable and cause vibrations and noise. This type of problem can occur at the common rail fuel injection systems, where the function of the high-pressure pump is dependent on this valve (Petrea *et al.*, 2018). A good way to determine if a ball check valve is suitable or not is to calculate the Reynolds number for the flow passing through the valve using the proposed design and working parameters.

The purpose of our paper is to provide a comparison between most common check valves used in industry, the design differences between them and their dynamic characteristics. Research and development of new solutions for hydraulic systems is necessary and implicitly for valves. It is sustained by the global demand for fluid transportation over long distances along with the urban agglomerations, the development of hydraulic systems and manufacturing processes in the industry.

2. Common Types of Check Valves Used in Hydraulic Systems

Two categories of check valves are presented in this paper. The first category is the Swing Check Valves (Fig. 2), which have at least one flat disc that rotates on a hinge pin and the second category is represented by the Lift Check Valves (Fig. 3) (Val-Matic, 2011).

Fig. 1 shows the most common check valves used in the industry divided into two categories including different types of valves, depending on their design.

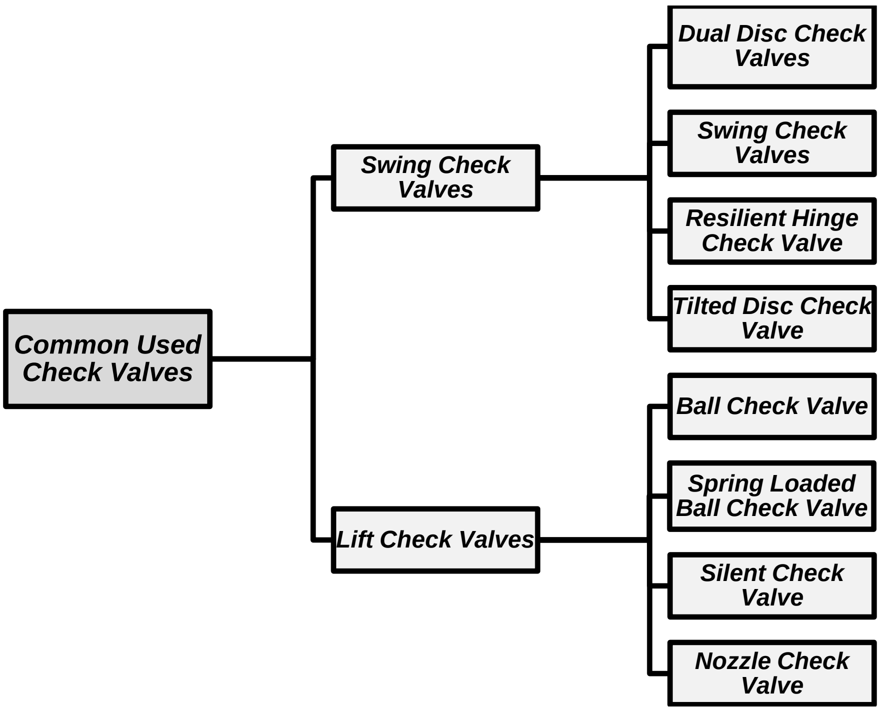
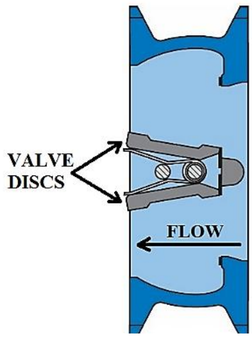


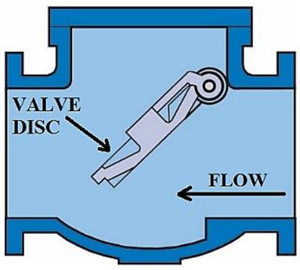
Fig. 1 – Types of check valves commonly used.

After several investigations and experiments done on the Swing Check Valves and Lift Check Valves, it has been observed that the valves of the first category are more susceptible to slam than the second one, except Ball Check Valve (Val-Matic, 2011). Some Lift Check Valves, like Spring-Loaded Ball Check Valve, Silent Check Valve and Nozzle Check Valve have the closure assisted by a spring which helps the valve closure process and prevents the creation of a reverse flow. Ideally, a check valve should close exactly when the flow direction is reversed (Turesson, 2011). Also, reverse velocities of the flow are directly influenced by the slope or pipeline orientation (Rahmeyer, 1996).

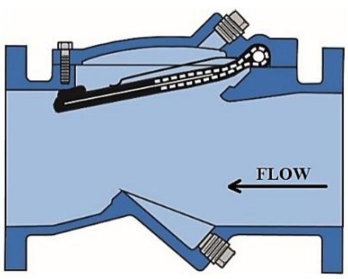
In Fig. 2 are represented four types of Swing Check Valves, all have something in common: the discs as a sealing element. These type of valves are most used in water pumping systems and have the advantage of being low cost, have low head losses and open and close depending on the direction of fluid flow (Val-Matic, 2011). The disadvantage is that the valve closure is dependent on the fluid flow, and when the flow is reversed the occurrence risk of the valve slam is very high.



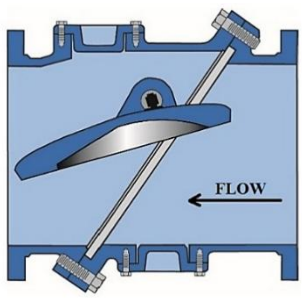
a) Dual Disc Check Valve



b) Swing Check Valve



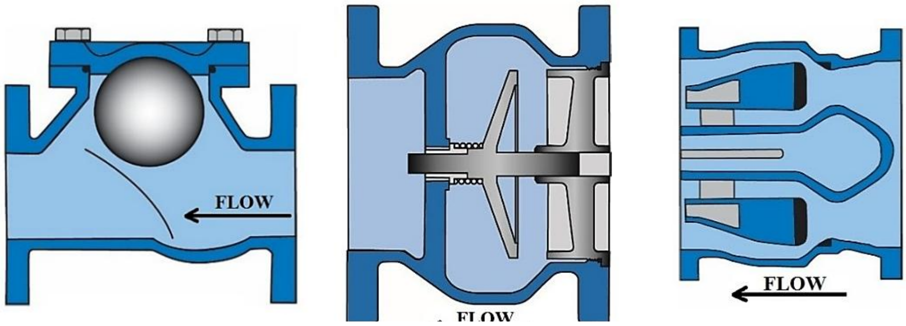
c) Resilient Hinge Check Valve



d) Tilted Disc Check Valve

Fig. 2 – Types of Swing Check Valves (Val-Matic, 2018).

Fig. 3 presents three types of Lift Check Valves, where two of them have in their assembly a spring that helps the valve to close very fast, such as the Silent Check Valve and the Nozzle Check Valve. The Ball Check Valve performs the closure depending on the reverse flow and is more prone to valve slam. These types of valves are an excellent choice for system types where a rapid flow reversal may occur. Some advantages of the check valves having a spring in their assembly are the sealing elements having a short travel distance to and from the seat and few elements subjected to load and wear (Flowserve, 2010).

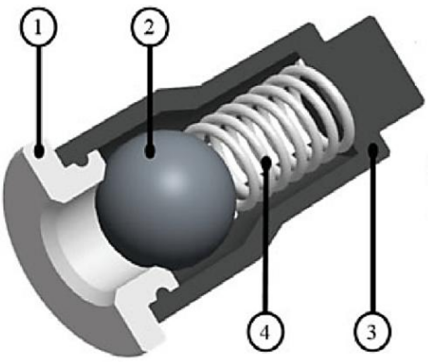


a) Ball Check Valve *b*) Silent Check Valve *c*) Nozzle Check Valve

Fig. 3 – Types of Lift Check Valves (Val-Matic, 2018).

Some studies have shown, that to prevent a check valve slam, the valve must close very quickly before the reverse flow develops or to close very slowly once the reverse flow has been created. In order to prevent it, at the design stage it is necessary to consider the following recommendations (Val-Matic, 2018):

- The disc must have low inertia and reduced friction;
- A short travel distance of the disc or sealing element;
- The motion of the sealing element should be assisted with springs;



1 – Spherical Seat; 2 – Steel Ball; 3 – Valve Body; 4 – Helical Spring

Fig. 4 – Spring-Loaded Ball Check Valve (Pendzialek *et al.*, 2016).

Spring-Loaded Ball Check Valves are the most commonly used in industry, especially in the automotive sector. These types of valves are used on systems where it is necessary to maintain a demand pressure, such as a pump that compresses the fluid and sends it to the accumulator. In this case, the valve is designed to prevent the fluid from returning to the pump's compression chamber.

3. Dynamic Behaviour of Check Valves in Hydraulic Systems

Significant research has been carried out to understand the dynamic closure characteristics and therefore the slam characteristics for different types of check valves. The experimental setup used to find the dynamic characteristics can be seen in Fig. 5. The check valve to be tested is installed immediately after the reservoir, and the pressure transducer after the valve records the pressure during the test. Also, it has been used the main valve at the end of the circuit in order to open and close it, and a secondary pump for increasing the flow and thus the pressure in the system for reverse flow simulation.

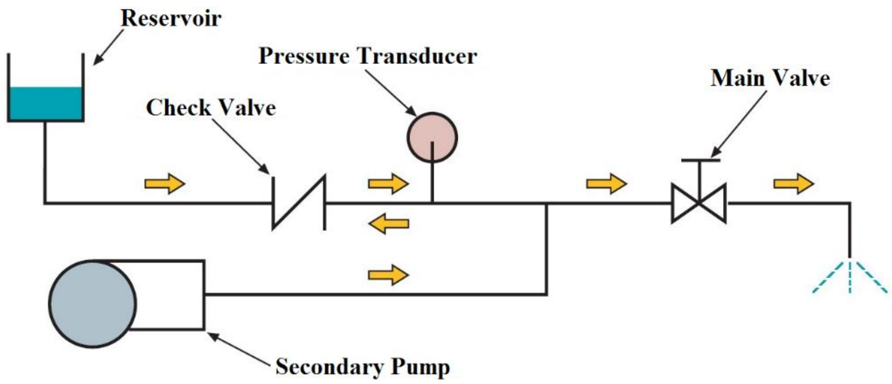


Fig. 5 – Experimental setup of check valves testing (Ballun, 2007).

By opening the main valve, the forward flow was established, and the check valve automatically opened. To simulate a valve slam and to observe the valve's behaviour, the secondary pump was turned on and started to provide more flow and pressure in the system. The main valve and the check valve are still open at this point, and the check valve closure cannot be triggered. By closing the main valve in the system, a high-velocity reverse flow is created, which quickly closes the check valve and therefore the valve slam occurrence. When the flow rate in a hydraulic system is suddenly changed, the kinetic energy of the fluid flow turns into pressure (Val-Matic, 2018).

In Fig. 6 it is shown an example of pressure trace recorded by the pressure transducer during the experimental test and where each sequence associated with the figure is exemplified as follows (Val-Matic, 2018):

A - Reservoir pressure;
A-B - Main valve closure, check valve starts to close;
B - Forward flow is stopped, the check valve continues to close;
B-C - Creation of reverse flow;
C - Valve disc hits the seat/Complete closure of the check valve;
D - Slam pressure due to sudden reverse flow stoppage;
E - Pressure from the secondary pump.

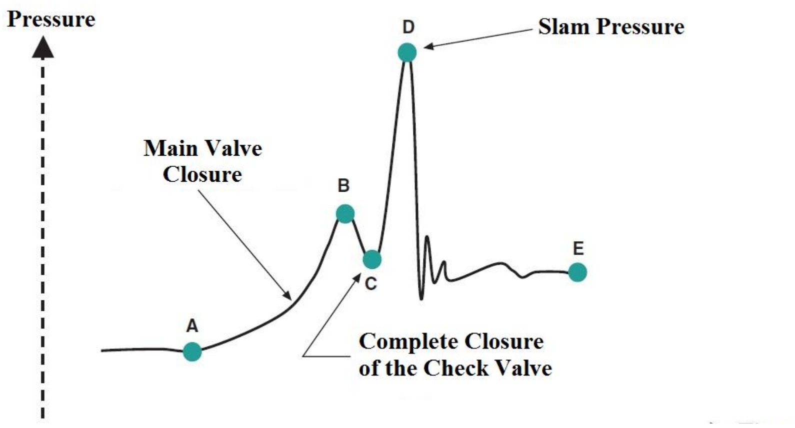


Fig. 6 – Example of pressure trace with valve slam (Ballun, 2007).

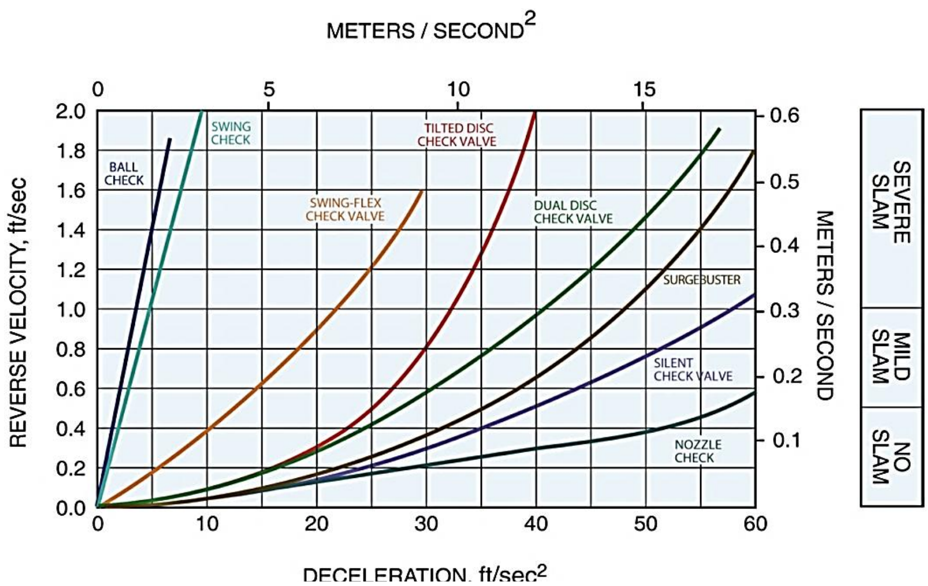
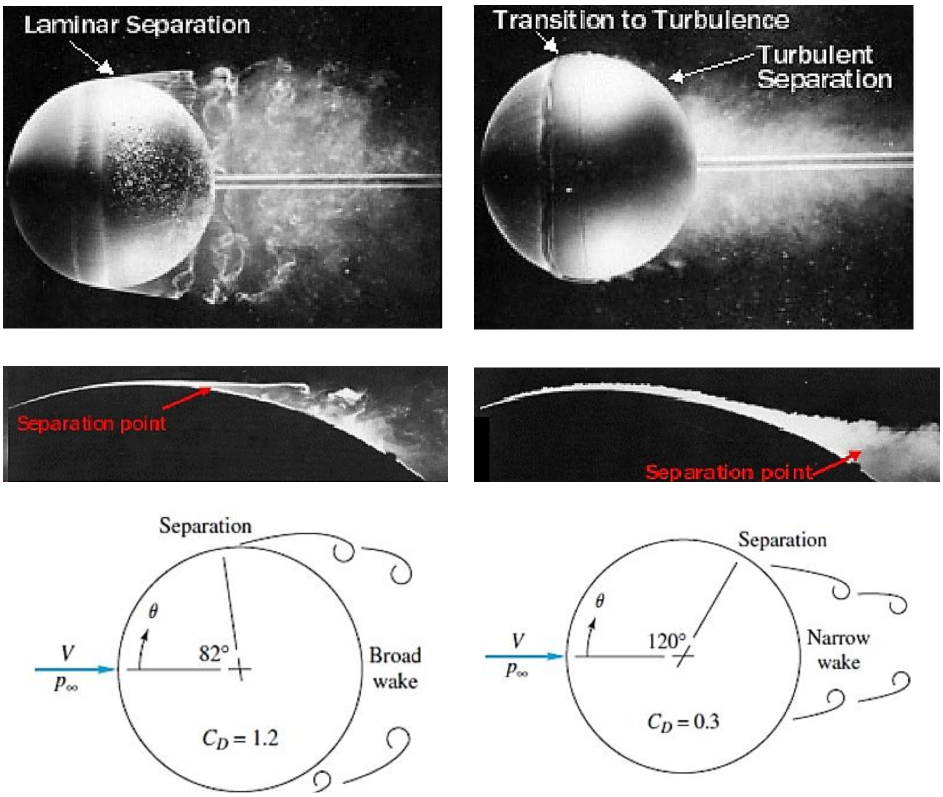


Fig. 7 – Dynamic characteristics of different types of check valves (Val-Matic, 2011).

The test results of different types of check valves using the presented test methodology can be observed in Fig. 7, where they are plotted according to their closure characteristics. It can be noticed that the best non-slam characteristics have the check valves that have a spring in their assembly that facilitates a rapid closure. Also, it can be said that the spring-loaded ball check valve has approximately the same characteristics.

4. Fluid Flow Regimes in an In-Line Ball Check Valve

The balls in the assembly of the check valves are subject to high pressures and high velocity flows, where some forces act on the ball, and one of them is the drag force. The drag force of a ball in a fluid depends mainly on the properties of the fluid, the speed of the fluid, the shape and the size of the object (Bakker, 2006). It can be said that the drag force depends on the shape of the object and the Reynolds number.



a) Laminar flow over a sphere *b*) Turbulent flow over a sphere

Fig. 8 – Flow regimes separations points (Bakker, 2006; Castaldi, 2015).

Experimental investigations have been demonstrated that, according to Reynolds number, the fluid flow passing over the ball can have different regimes (Liquids Flow Study, n.d.):

- Re < 2000 - Laminar Flow;
- 2000 < Re < 3000 - Transition Flow;
- Re > 3000 - Turbulent Flow;

In Fig. 8 it can be observed the flow separation point over a sphere at two different flow regimes, laminar and respectively turbulent flow regime. It is well known that the process of fluid flow around a spherical or cylindrical body is accompanied behind by a vortex, which induces vibrations and the resulting forces act on the body in a direction transverse to the flow (Grinis *et al.*, 2012).

At very low values of Reynolds numbers the flow remains attached to the sphere all over the circumference, and as the velocity of the flow increases and the Reynolds number reaches a value of 1000, the separation point of the flow over the sphere stays at a stable position of approximately 82° from the front stagnation point. Going moreover, at a value of 100000 the flow is completely turbulent, and the separation point moves to 120° from the front stagnation point (Boundary Layer Theory, n.d.). The ball check valves which reach during functionality Reynolds numbers over 2000 are more susceptible to noise and vibrations because of the turbulent flow regime.

5. Conclusions

Check valves are a real necessity for almost all industries, and the selection criteria depend primarily on the type and size of the hydraulic system. In water pumping systems, Swing Check Valves are the best choice because, due to the size of the pipes, the valves can be made in large dimensions at low cost and their maintenance can be done very easily. It is true that the Swing Check Valves are more prone for valve slam than the Lift Check Valves which have a spring assisted closure. However, to prevent a valve slam, the flow from the entire system must be precisely controlled in order to close the valve very slowly. Lift Check Valves, such as Spring-Loaded Check Valves, are most often used in high-pressure systems, where a reverse flow is not allowed. They have the advantage of fast closing due to the short stroke of the sealing element. As a disadvantage of ball check valves, with or without spring assisted closure, is that in some systems produce a disturbing noise. Having the knowledge about self-excited vibrations of the ball, depending on Reynolds's number, it will be much easier to develop new valve types considering this feature. Due to a multitude of hydraulic systems and applications, there is no single check valve design that can satisfy the requirements of all systems and should be selected according to the requirements of each hydraulic system in part. A future work will be carried out to establish other dynamic characteristics of check valves with an impact in various hydraulic systems.

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COMPORTAMENTUL DIFERITELOR TIPURI DE SUPAPE UTILIZATE ÎN SISTEMELE HIDRAULICE

(Rezumat)

Majoritatea industriilor din ziua de astăzi funcționează cu ajutorul unor sisteme hidraulice complexe, iar cercetarea și dezvoltarea lor trebuie să continue pentru a oferi soluții viitoare mai bune. Funcționalitatea sistemelor hidraulice este asigurată de o mare varietate de supape, iar fiecare supapă are un design și un scop bine definit. Lucrarea oferă o prezentare generală cu privire la cercetări efectuate pe cele mai utilizate supape de sens în industrie și a comportamentului acestora în ansamblul sistemelor hidraulice.