"HENRI COANDA"
AIR FORCE ACADEMY
ROMANIA

"GENERAL M.R. STEFANIK"
ARMED FORCES ACADEMY
SLOVAK REPUBLIC

INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER
AFASES 2015
Brasov, 28-30 May 2015

EXPERIMENTAL SETUP FOR STUDYING PROPERTIES OF POWER GASES

Tomáš Lukáč*, Vladimír Horák*, Linh Do Duc*, Dalibor Rozehnal*

*Faculty of Military Technology, University of Defense, Brno, Czech Republic

Abstract: *The paper deals with the development of the experimental device using for the research and study of the phase behavior and state characteristics of pressurized power gases for liquid propellant powered guns for fast shooting cadence and for long bursts of shooting. Further for the development of the device for the gun's recoil simulation, the device for simulation the sound effect of the RPG-7 launcher for a shooting training, and for the study of using of a liquid gas as the emergency power gas generator for pneumatic systems. Requirements for regulating the duration and timing of the power gas delivery follow the electronically driven and electrically operated solenoid valve. Several kinds of solenoid valves design patterns and principles of driving are closely described. The valve measured characteristics and some results of testing on the proposed experimental device are presented.*

Keywords: *power gas, gas guns, solenoid valve, electrical driving*

1. INTRODUCTION

The proposal to develop an experimental device for the purpose of research and study of the phase behavior and state characteristics for various pressurized power gases resulted from the need to obtain experimental data e.g. for:

- The study of the phase behavior and characteristics of power gases for gas guns and verification of mathematical models [1].
- Quantifying limits of use of the liquid propellant powered guns for fast shooting cadence and for long bursts of shooting.
- Development of a variable device for the gun's recoil simulation, whereas increased power gas consumption is supposed.
- Development of a simulation device for the sound effect of the RPG-7 anti-tank grenade launcher for a shooting training [2].
- The study of using of a liquid gas as the emergency power gas generator for pneumatic systems of aircraft and military vehicles.

This device should allow arbitrary regulation of the amount and the rate of flow of a power gas being discharged from a storage tank. Further, the device should be provided with a control system regulating the duration and timing of the power gas delivery.

In liquid propellant powered guns, a mechanical drive is used for the rate valves within the systems of guns. The design involving an electronically driven and electrically operated solenoid valve follows the requirements mentioned above.

2. ELECTRICALLY OPERATED VALVES

The valve is controlled by an electric current flowing through a coil, so electrically operated valve is also known as solenoid valve. The most used types of valves are 2/2-way solenoid valves, which switches flow on or off and 3/2-way solenoid valves, which control the flow between the two outlet ports. First number indicates a number of ports and second number indicates number of possible states. For special application are also used 4/2, 5/2, 5/3, 5/4 or 5/5-way valves. According to an internal arrangement of valve control system, solenoid valves are divided to a direct acting and indirect or pilot operated valves. As control current can be used direct or alternating current, where solenoid valves for alternating current systems and applications have a build-in rectifier onboard.

2.1 Direct acting valves. Direct acting valves, sometimes referred as electromagnetic solenoid valves, can be used to control a lower pressure because a solenoid can generate only a proportional force according to its dimensions. Lower pressures require a smaller force, needed to switch, open or close a valve. An approximate relationship between the required solenoid force, the fluid pressure, and the orifice area for a direct acting solenoid valve is:

$$F_S = p\,A = p\,\frac{\pi\, d^2}{4} \qquad (1)$$

where F_S is the force acting on the solenoid valve, p is the fluid pressure, A is the valve orifice area, and d is the orifice diameter.

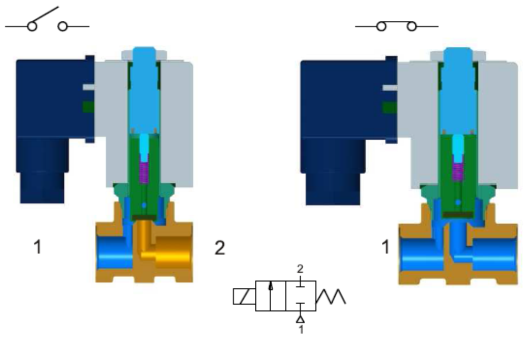

Fig. 1. Direct acting solenoid valve [3]

Fig. 1 shows a cut view of 2/2-way normally closed direct acting valve.

A direct acting solenoid valve typically operates in the range of times from 10 to 30 milliseconds.

2.2 Indirect acting pilot operated valves. These valves use fluid pressure to assist operation, which is used to generate the high valve forces and a small solenoid controls usage of fluid pressure. In some solenoid valves the solenoid acts directly on the main valve. Others use a small, complete solenoid valve, known as a pilot, to actuate a larger valve. Piloted valves require much less power to control, but they are noticeably slower. The operation time of a piloted valve depends on its size. Typical values are from 15 to 150 milliseconds. Fig. 2 shows a cut view of 2/2 normally closed pilot operated valve.

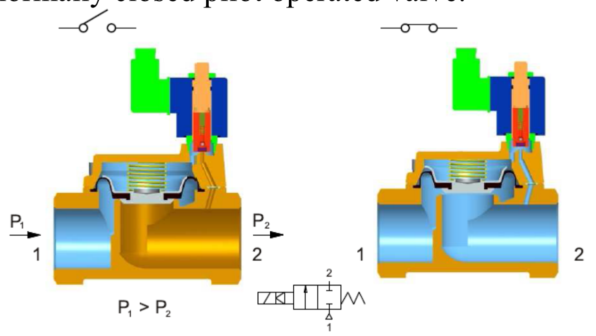

Fig. 2. Pilot operated solenoid valve [3]

Fig. 3 shows an indirect operating valve with forced lifting.

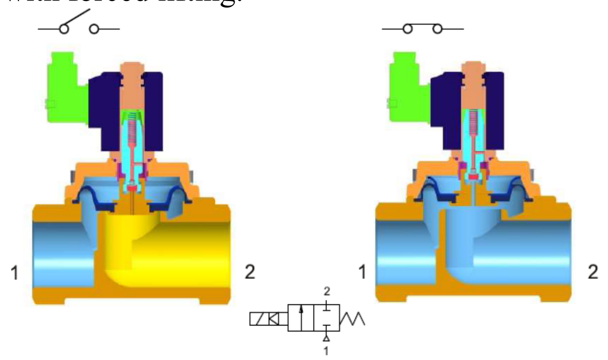

Fig. 3. Indirect operated solenoid valve with forced lifting [3]

2.3 Valve actuators. A valve actuator is the mechanism for opening and closing a valve. Power-operated actuators, using gas pressure, hydraulic pressure or electricity, allow a valve to be adjusted remotely, or allow rapid operation of large valves. Power-operated valve actuators may be the final elements of an automatic control loop which automatically regulates some flow, level or other process. Actuators allow an intermediate positioning. Some valve actuators include switches or other ways to remotely indicate the position of the valve [4].

Both actuator signals and operation commands of the DCS are processed within the actuator controls. This task can in principle be assumed by external controls, e.g. a programmable logic controller (PLC). Controls use the switchgear to switch the electric motor on or off depending on the signals or commands present. Another task of the actuator controls is to provide the distributed control system with feedback signals, e.g. when reaching a valve end position. The electrical connection can be designed as a separately sealed terminal bung or plug/socket connector. For maintenance purposes, the wiring should be easily disconnected and reconnected [5].

Fieldbus technology is increasingly used for data transmission in process automation applications. Electric actuators can therefore be equipped with all common fieldbus interfaces used in process automation. Special connections are required for the connection of fieldbus data cables.

In their basic version most electric actuators are equipped with a hand wheel for operating the actuators during commissioning or power failure [5].

3. VALVE MANAGEMENT OPTIONS

Depending on used type of signal to switch or operate a valve, valve control circuits can be divided to analog and digital.

3.1 Analog valve management. Analog valve management uses analog signal to operate a solenoid valve. For mono-stable solenoid valve, constant presence of control signal is necessary as the valve is in the switched-on state. The main advantage of this sort of valve management is simple control circuits and easy maintenance. Disadvantage is higher consumption of electricity, depending on solenoid power consumption and the amount of time spent in switched state. In complicated applications with numerous valves, can be power consumption rather high. This disadvantage can be eliminated by using a bi-stable solenoid valves. A bi-stable solenoid valves contains a two solenoids, each for switching valve to one state and its control can be implemented by operating signals. This way of valves control rapidly decreases power consumption of whole system, as solenoids consume power only during the swift process of switching. As control circuits in simple applications can be used dedicated circuits, with or without a feedback, often represented by the time relays. Time relays are made as mechanical adjustable relays or digital programmable relays. Fig. 4 shows mechanical adjustable time relays.

Fig. 4. Mechanical adjustable time relays [6]

Some kinds of digital programmable relays are equipped with digital display to simple adjustment or for showing a working state and time, which is shown on Fig. 5.

Fig. 5. Digital programmable relay [7]

Time relay consists of one or more mechanical relays and timing circuit, which switches relays depending on time variable. Time periods can be adjustable from 10 ms to hundreds of hours and in combination with proper relay function time relay provides simple and effective method for automatization. Basic functions are delay ON/OFF, flasher function is repeating a loop of constant impulses, star/delta change-over allows switching between star and delta connection. Function for impulse generator generates one adjustable impulse.

3.2 Digital valve management. In advanced systems are simple control circuits merged in control units, which are able to control several valves at once. Control units include a logical circuit which is capable to operate connected valves and run simple diagnostic or check the states of connected valves. Specialized control units are equipped with RS232, USB or LAN interface and can be programmed and driven through PC to perform advanced tasks and applications, such a manufacturing processes, driving a manipulators or robotic systems. Fig. 6 shows Festo CECX modular automat for motion driving for advanced pneumatic applications.

Fig. 6. Modular controller CECX [8]

In modern automated or computer operated applications is an advantage to use a digital management system. In this case, each valve contains, except a solenoid, or motor in case of actuators a logical circuit onboard which allows us to provide a digital link between control unit and a valve. This system of driving is frequently used to drive valve actuators. It allows more valves or actuators to be connected on one link, depending on bus width, and allows us to build simple installation. Fig. 7 shows an actuator from Siemens Acvatix technology.

Fig. 7. Siemens Acvatix actuator [9]

Communication between valves and control units contains except the operating signals, a data communication, which includes the status reports, advanced control possibilities and makes maintenance and resolving of a problems much easier and faster. Digital connection allows us to connect the valves direct to the dedicated computer or to the module with control electronics, which can be connected to the computer. Operating software with drivers running on the computer can provide a complete control of connected valves, running scheduled tasks, maintenance or system checks. If the Ethernet connection is present, through Ethernet cable or wireless network, operating software can provide LAN or internet access to manage whole system.

"HENRI COANDA"
AIR FORCE ACADEMY
ROMANIA

"GENERAL M.R. STEFANIK"
ARMED FORCES ACADEMY
SLOVAK REPUBLIC

INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER
AFASES 2015
Brasov, 28-30 May 2015

4. POSSIBILITIES OF MEASUREMENT ON THE EXPERIMENTAL SETUP

The experimental setup for studying the properties of power gases was designed to meet requirements stated in the introduction of this paper. Presented tests were performed with the carbon dioxide.

4.1 Arrangement of experimental setup. The block schematic diagram of the presented experimental setup is shown in Fig. 8.

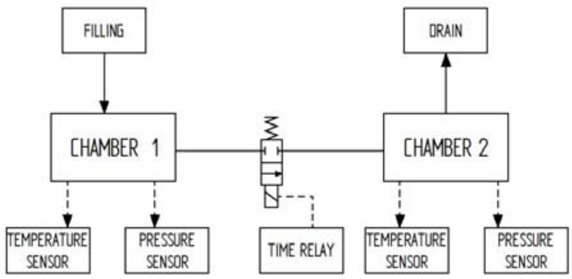

Fig. 8. Block schematic diagram

The experimental device contains two high-pressure chambers of volume 91 cm^3 connected by a high pressure hose. Access between chambers is provided through the electrically driven 2/2-way pilot operated solenoid valve GSR Type 46, rated for maximum pressure 10 MPa.

The time courses of pressure within the both chambers are measured by the piezo-resistive pressure sensors DMP 333 with measure range from 0 to 25 MPa.

Temperatures of both chamber walls are measured by resistive temperature sensors Jumo T90 2050 with measure range from -50 to 300 degrees Celsius.

Measured data processing is performed by the software LabVIEW from National Instruments.

The view of the experimental setup is shown in Fig. 9.

Fig. 9. View of experimental setup

4.2 Discharge characteristics of valve. These characteristics represent the dependence of the fluid discharged mass Δm form the chamber 1 into the surrounding atmosphere versus the time of the valve opening. This time is controlled by the relay ElkoEP PDR-2A.

The valve discharge characteristics for gaseous, liquid and supercritical state of the carbon dioxide are shown in Fig. 10. These characteristics enable us to define the power gas discharged mass for various valve opening times and for various power gas states. The minimum opening time of the valve is 20 ms.

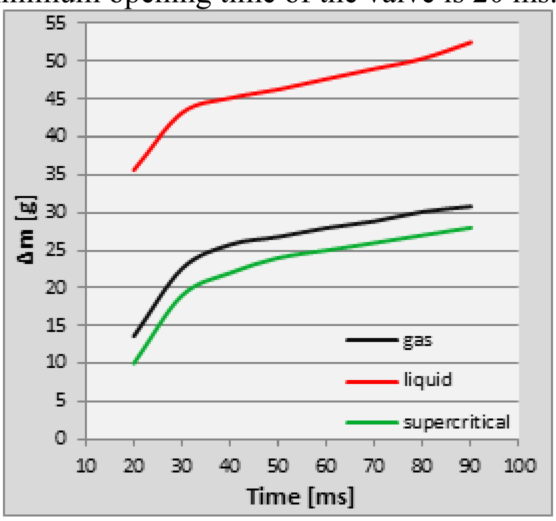

Fig. 10. Valve discharge characteristics

The dependence of the discharged mass on the opening time (see Fig. 10) is nearly linear for higher opening times. The deviation from the linear course is given by the delay of the solenoid valve opening, which is about 10 ms.

Each the discharge measurement has been started with the same initial mass of the carbon dioxide 60 g and the same initial pressure 5.5 MPa. Initial pressure for the supercritical state is 8.2 MPa.

The corresponding dependency of the median discharging fluid mass flow rate during the time of the valve opening is shown in Fig. 11.

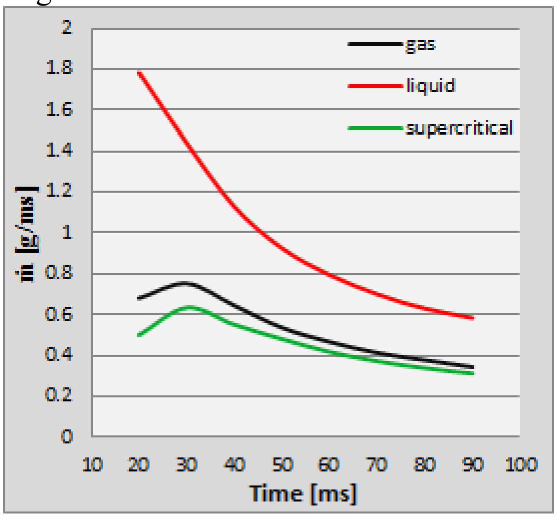

Fig. 11. Discharging mass flow rate

4.3 Measurement of depressurization. The time course of pressure within the chamber 1 during the discharge of gaseous CO_2 into the surrounding atmosphere is shown in Fig. 12.

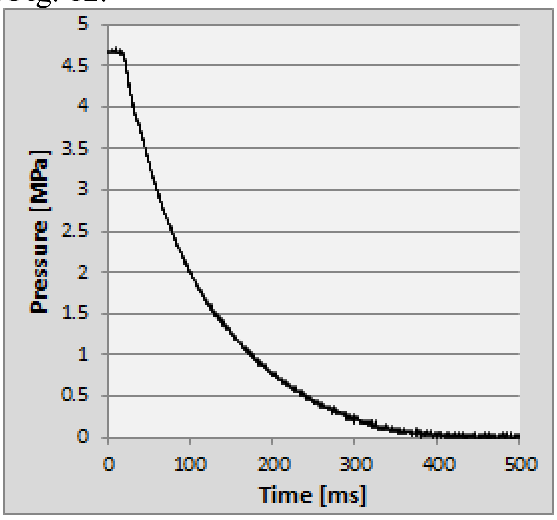

Fig. 12. Depressurization of gaseous CO_2

The analogical discharge of a two-phase fluid into the surrounding atmosphere is presented in Fig. 13 for various amounts of the liquid CO_2 filled into the chamber 1. The discharge aperture of the chamber 1 is 4 mm. The time courses of pressure from left to right correspond to the liquid CO_2 filling 32, 35, and 40 g.

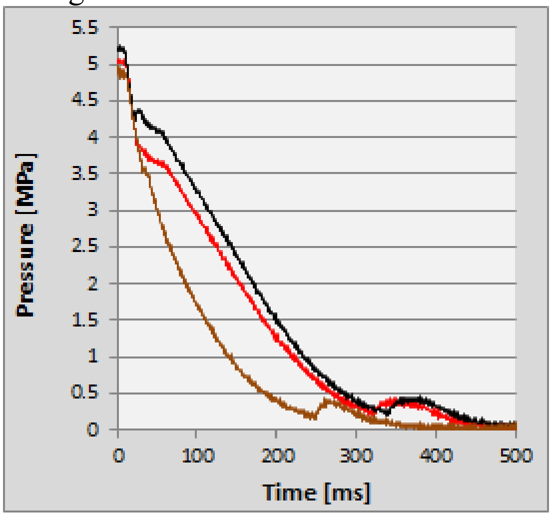

Fig. 13. Depressurization two-phase fluid

The first stage of depressurization, after the valve opening delay, represents discharge of gaseous CO_2 above the liquid level. This stage of depressurization corresponds to the pressure course in Fig. 12.

In the second stage between 40 and 80 ms, we can observe thermal non-equilibrium effects of two-phase fluid flow which are present due to rapid depressurization.

If the pressure and temperature drops under the CO_2 triple point values, the dry ice is created. The third stage of the discharge process is caused by the formation and following sublimation of the dry ice.

4.4. Pressurization of second chamber. When the solenoid control valve is open, the two-phase fluid starts to discharge from the chamber 1 through the valve and the connecting pipe into the chamber 2 (see Fig. 8 and Fig. 9).

Measured time courses of pressure within the both chambers during the pressurization of chamber 2 are shown in Fig. 14 for the initial liquid CO_2 filling in the first chamber 40 g.

In the time about 25 ms, we can also observe the thermal non-equilibrium effects of two-phase fluid flow on the chamber 1 pressure curve. In the time about 90 ms, the process of the chamber 2 pressurization is completed. The final value of pressure in the connected chambers is 3.5 MPa.

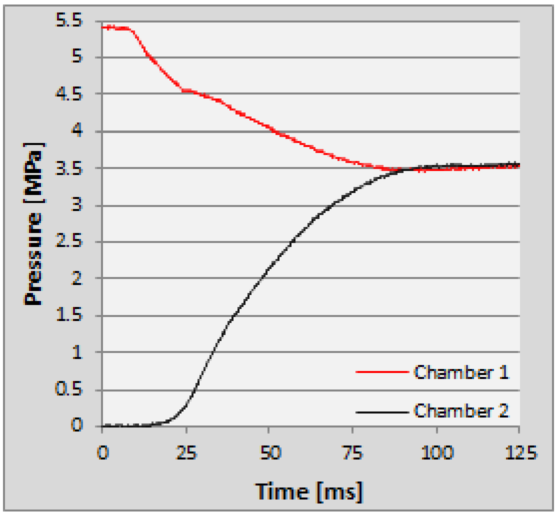

Fig. 14. Time courses of pressure during pressurization of chamber 2

4.5 Short-interval periodic discharge. Possibilities of the presented experimental setup to examine various short-interval periodic discharge processes are proved by the example of pressure curves, which is shown in Fig. 15.

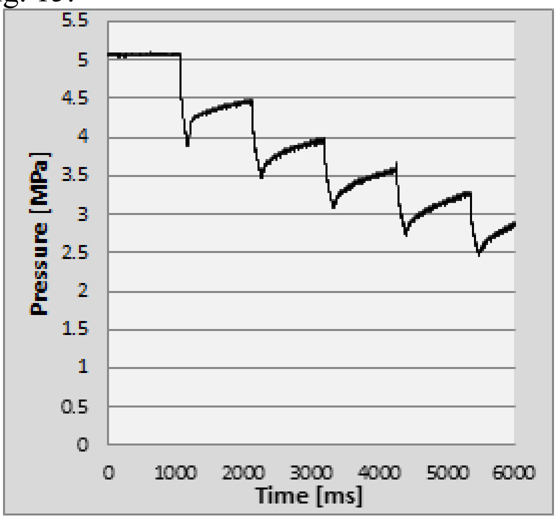

Fig. 15. Periodic discharge

Here, the solenoid control valve opens periodically for 50 ms at intervals of 1 second. The periodic discharge flow to the surrounding atmosphere was stabilized by using the orifice of diameter 1.6 mm that was placed behind the control valve. The initial liquid CO_2 filling was 70 g.

We can observe limited pressure stability of the system. The pressure gradually drops due to the decrease in temperature and corresponding decrease in saturated pressure of carbon dioxide.

5. CONCLUSIONS & ACKNOWLEDGMENT

The presented experimental setup will be widely used for the research work of authors. It is supposed using mainly for:

- The comprehensive study of properties of power gases for gas guns.
- The study of thermal non-equilibrium effects of two-phase fluid flow during the rapid depressurization.
- The verification of mathematical models of two-phase fluid flow.
- The study of stability of systems using the liquid propellant during the short-interval periodic discharge processes.
- The development of device for the simulation of small gun's recoil and the sound effect of the RPG-7 shooting.
- The study of using of a liquid gas as the emergency power gas generator for pneumatic systems.

The work presented in this paper has been supported by the institutional funding PRO K216 "Support of Research, Experimental Development, and Innovation in Mechanical Engineering" and by the Specific Research Support Project of the Faculty of Military Technology SV K216.

REFERENCES

1. Horák, V., Do Duc, L., Vítek, R., Beer, S., Mai, Q. H. Prediction of the air gun performance. *Advances in Military Technology*, vol. 9 (2014), no. 1, p. 31-44.
2. Mai, Q. H., Horák, V., Do Duc, L. Sound effect of RPG-7 antitank grenade launcher for shooting training. *Advances in Military Technology*, vol. 9 (2014), no. 2, p. 49-60.
3. *Operation description of solenoid valves*. Mahrlo. (Retrieved November 17, 2014).
4. Nesbitt, B. (ed.), *Handbook of Valves and Actuators*, Chapter 12 Actuators. Elsevier (2007).
5. Cooper, E. *For Gate Valves, Actuation is not Turn Turn Turn. Valve World Americas*, vol. 5 (June 2014), no. 6.
6. *Haustechnik Katalog 3073 DE GB*. Eberle, [online, retrieved January 15, 2015].
7. http://www.safestb2b.com/uploads/digital-electrical-timer-relay-switch-time-ad-c9cf6.jpg, [online, retrieved January 15, 2015].
8. *Modular Controllers CECX Catalog*. Festo, [online, retrieved January 16, 2015].
9. *Acvatix Valves and Actuators Catalog*. Siemens Buildings Technologies, [online, retrieved February 2, 2015].