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# MEASUREMENTS OF SHOCK COMPRESSION

# MĚŘENÍ RÁZOVÉ KOMPRESE

**Abstract**

This article was written based on the topic of student's dissertation. This is the research of shock phenomena which may occur, under certain conditions, by operation of displacement compressors with the Built-in pressure ratio. These phenomena are called the Shock compression and the Shock expansion or we can use terms "Under-compression" and "Over-compression". The contribution describes current possibilities of a measurement Shock compression at the experimental measuring stand in Laboratory of displacement compressors which is owned by Department of Power Engineering, Faculty of Mechanical Engineering and VŠB – Technical University of Ostrava. The contribution deals with the analysis of the experiment and as well as the results obtained which confirm some the conclusions of the Basic physical model.

**Keywords**

Shock Compression, Under-Compression, Screw compressors, Build-in Pressure Ratio

**Klíčová slova**

Rázová komprese, Šroubové kompresory, Vestavěný tlakový poměr

**Abstrakt**

Tento příspěvek vznikl na základě tématu disertační práce studenta. Jedná se o výzkum rázových jevů, ke kterým může, za určitých podmínek, docházet při provozu objemových kompresorů s vestavěným kompresním poměrem. Tyto jevy se nazývají rázová komprese a rázová expanze. Příspěvek popisuje současné možnosti měření rázové komprese na experimentálním měřicím standu v Laboratoři objemových kompresorů, jež spadá pod Katedru energetiky, Fakulty strojní, Vysoké školy báňské – Technické univerzity Ostrava. Příspěvek se věnuje rozboru experimentu a také získaných výsledků, které potvrzují některé závěry základního fyzikálního modelu.

**Klíčová slova**

Rázová komprese, Šroubové kompresory, Vestavěný tlakový poměr

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# 1 INTRODUCTION

The production of compressed gas, especially air, is an energy-intensive process. Different sources speak about different numbers but in general approx. 30 % of the total energy consumption is used globally for an operation of compressors.

Compressors are machines widely used in all areas of human activity. It is theoretically possible to say that the gas compression process is thoroughly explored. However, with each new type of compressor, we can encounter phenomena that were not anticipated during operation.

And so it is with the shock phenomena that may occur under certain conditions during operation of displacement compressors with the rotary movement of the piston(s) and with build-in pressure ratio.

The designers' intention was certainly not to make unusual states and phenomena during operation. These states can cause pressure pulsations, vibrations, greater stress on bearings, losses of energy and total instability of operation. However, the built-in pressure ratio is a design limitation of the machine. Such a compressor can compress the gas within working space by a given pressure limit only. By nominal operating conditions, it is compressing to the nominal pressure of the gas.

If there is an imbalance of pressure at the compressor outlet with the pressure in the piping system occurs problems and these are called according to type: "Shock compression and Shock expansion". This article will focus on trying to create an experiment and measure the influence of the Shock compression to the Instantaneous power consumption of a screw compressor drive. The resulting data should in principle coincide with the results of the basic physical model which was previously calculated.

# 2 AIMS OF THE EXPERIMENT

Measurement of shock compression was realized of the following reasons:

1. Verify the assumption based on available scientific literature on this phenomenon. This assumption is: "*If it occurs during operation of a displacement compressor with the rotary movement of the piston(s) and with built-in pressure ratio to the Shock compression. This will result in an increase of the Instantaneous power consumption of a screw compressor drive.*"
2. Verify the assumption based on available scientific literature on this phenomenon. This assumption is: "*With the increasing intensity Shock compression, or with increasing pulse intensity, also increases the value of Instantaneous power consumption of a screw compressor drive which is especially needed to overcome the pressure energy of the gas, which flowing back to the compressor unit.*"
3. Process and evaluate measured data and provide conclusions and recommendations for the future analysis of the examined issues.
4. The most important point from the technical point of view was to test the possibilities and limits of the existing experimental measuring stand in Laboratory of displacement compressors. Evaluate usability and status of existing gauges and possibly propose important points which must not be overlooked in the design of new experimental measuring stand.

## 3 THEORETICAL ANALYSIS OF MEASURED PHENOMENON

The shock compression occurs in the case that is built-in pressure ratio $\pi\,[-]$ is lower than total pressure ratio of pipe system $\sigma\,[-]$ or compression capability of the compressor is lower than the gas pressure in the piping system $p_D\,[Pa]$. This transformation is also called External compression and eg. in the operation Roots blowers is necessary for the working process. In this case, it is a negative phenomenon. The process is shown in Figure "Fig. 1".

First is the gas isothermally compressed from the pressure on the inlet of compressor $p_1\,[Pa]$ to pressure on the outlet from working space of compressor respectively to the pressure at the outlet of compressor unit $p_2\,[Pa]$ which is lower than the pressure in piping system $p_D\,[Pa]$. By connection workspace of a compressor or a compressor unit with the pipeline on the outlet occurs immediately the shock compression to the pressure $p_D\,[Pa]$.

The gas which is in the outlet pipeline has higher pressure and it tends to flow back to the workspace of compressor or compressor unit. Generally that is into the lower pressure area. The compressor drive must give additional compression work to turn around this reverse flow. If the reverse flow reaches the working space of compressor so this gas can transform part of its enthalpy to the gas which is still compressed in the working space. This may result in an increase of the temperature of the gas which has been compressed in this moment. This would lead to another increase of the compression work. The hatched area represents the total increase of compression work $A_{ztr}\,[J]$ from all sources.

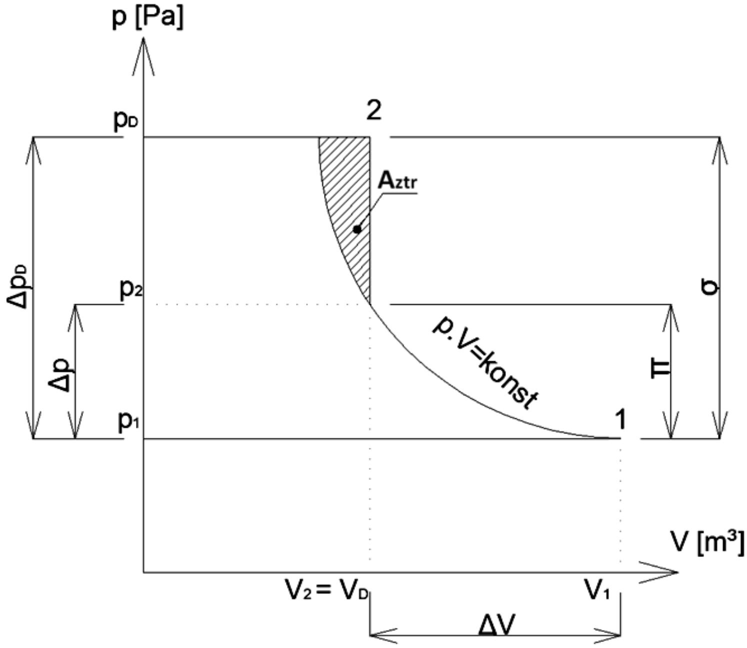


**Fig. 1** The ideal indicator p-V diagram of Shock compression [Own creation]

The Shock compression is a negative phenomenon which may result in an increase of the compressed gas temperature, in pressure pulsations, in the greater stress on bearings and last but not least, in the increase of the Instantaneous power consumption of a screw compressor drive and in the increase of the operating costs to the compressor unit.

The equation (1) describes that Power consumption of compressor depends on the Compression work $A_k\,[J]$ and Main rotor speed $n_H\,[s^{-1}]$. When is change one or both parameters is there an increase of compression work by value $A_{ztr}\,[J]$ and this will also increase the power consumption of compressor $P\,[W]$. [3]

$$P = A_k \cdot n = (A_k + A_{ztr}) \cdot n_H \; [W] \tag{1}$$

Where:

$A_k$ – Compression work $[\mathrm{J}]$,

$A_{ztr}$ – The increase of Compression Work “The Loss-Compression work” $[\mathrm{J}]$,

$n_H$ – Main rotor speed $[s^{-1}]$.

## 4 COMPRESSOR UNIT USED FOR EXPERIMENTS

In the Laboratory of displacement compressors is located the stabil compressor unit SE 25 with built-in Screw compressor NK 40 manufactured by company Liška a Kraus – KOMPRESORY spol. s r.o.. Currently, the company is known under the trademark ATMOS -CHRÁST, s.r.o .. Important technical parameters of this machine are written in the Table “Tab. 1” below.

**Tab. 1** Technical Data Sheet – Compressor unit SE25 with built-in Screw compressor NK 40 [1]

| Description | Value | Units |
|---|---|---|
| Type | NK 40 | - |
| Kind | Screw | - |
| Nominal “power” (Volume flow rate) | 25 – 35 | $m^3 \cdot h^{-1}$ |
| Nominal speed | 2750 - 4000 | $\min^{-1}$ |
| Outlet gauge pressure | 1 – 0,8 | $MPa - g$ |
| Number of stages | 1 | - |
| Cooling | Oil | - |
| Power of electric engine | 4 | $kW$ |
| Regulation | • Electric with pressure switch<br>• Pneumatic | - |

**Fig. 2** The compressor unit SE 25 [Own creation]

## 4.1 Description function of the compressor unit

The air is sucked through the air filter (1). Suction regulator (2) regulates the amount of sucked air depending on the pressure and amount of the air. The sucked air is transport in the toothed spaces of the screw rotors (3) to the discharge pipe. At the same time, oil is injected into the compressor suction side. The oil seals the rotors of the compressor and ensures their lubrication. The oil transfers part of the compression heat out side of working space. The mixture of oil and air flows into the reservoir (4), where it occurs a separation of almost all oil. The rest, so called "Oil Mist" separates on the oil separator insert (5). On the bottom of the oil separator is located the minimum pressure valve (6). The air goes further into the air section of the cooler (7). The oil, that has taken the bulk of compression heat, flows into the oil section of the cooler (9). The optimum temperature of the cooling oil is provided by the thermostat (8). [1]

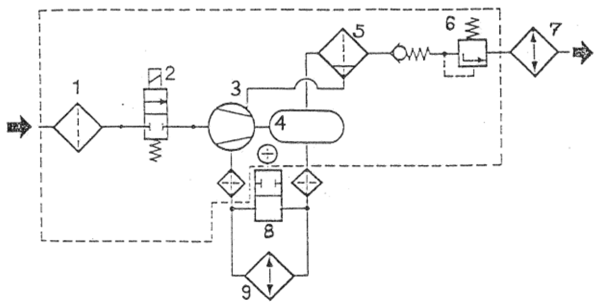


**Fig. 3** The scheme of the compressor unit SE 25 [1]

# 5 THE EXPERIMENTAL MEASURING STAND

The experimental measuring stand is located in the Laboratory of displacement compressors in the building of Faculty of Mechanical Engineering, VŠB – Technical University Ostrava. It is constructed from a whole range of machine components, fitting and partial meter runs. The experimental measuring stand was not designed and assembled to a measurement of Shock phenomena. From this reason, it was necessary to design an experiment which would allow this measurement with using existing equipment. In this chapter will be described the active part of the experimental measuring stand which was active during experiments with the Shock compression. The description will be in the direction of air flow.

The compressor unit SE 25 was connected to the experimental measuring stand by a pressure rubber hose with an internal diameter ½". At both ends of the hose were ball valves which were actively used during the experiments.

The first sub-section of the experimental measuring stand is a straight pipe section by dimension DN15 and pipe reduction DN15/DN40. Next component is a meter run with centric orifice plate DN50 PN40. This gauge is designed to measure of differential pressure which is needed for calculation of flow rate. To determine of flow rate are here manometer and thermometer well yet. In this case will be these gauges not active. The reasons are quite simple. It is the protection of U-tube before possible pressure pulsations but the main reason is that during experiments will be no air flow here. This part will be for an accumulation of compress air only.

Next part is the T-piece fitting. The upper branch is a bypass which is closed for the purpose of measuring of the Shock compression. The compressed air flows through the downer branch during open ball valve to the set of pressure cylinders, which are used for accumulation of compressed air for experiments.

The set of six pressure cylinders is the core of the experimental measuring stand. The five pressure cylinders have the volume 29 l except for the pressure cylinder No. 3, which can be changed and there are two variants of pressure cylinders by the volume 0,5 l and 1 l.

All pressure cylinders can be arbitrarily shut down from measuring with using ball valves. All pressure cylinders are equipped with analog manometers SUKU, Type 4301 and universal pressure sensors CRESSTO TMG 637 Z3F for measurement of air pressure. To the measurement of temperature inside of pressure cylinders are used thermoelectric temperature sensors JSP, FlexiTEMP 60 (T1560).

On the pipe between the pressure cylinder No. 2 and No. 3 is universal pressure sensors CRESSTO TMG 637 Z3F too. The same sensor is between the pressure cylinder No. 4 and No. 5. It can therefore easily record the values of air pressure in the pipe system if are the pressure cylinders closed.

The active part of the experimental measuring stand is shown schematically on the Figure “Fig. 4”. The detailed descriptions and parameters of individual gauges are listed in the “Protocol by the measurement – RK1”, see the literature [4] or [5].

The outlet side of the experimental measuring stand which is located on an upstream side the set of pressure cylinders, is not necessary for measurement influence of the Shock compression. From this reason is not in the article described.

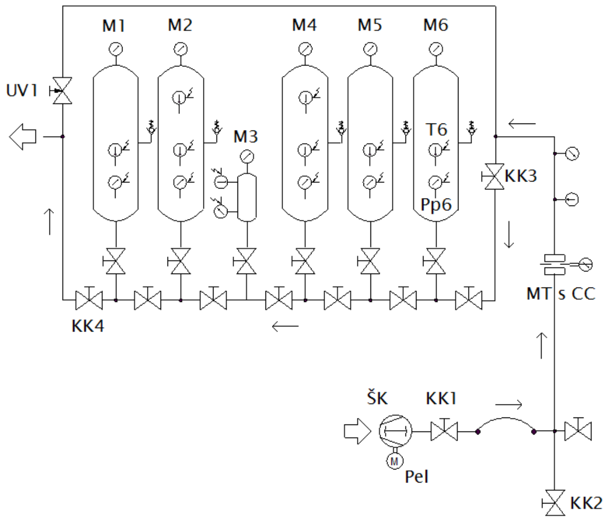


**Fig. 4** The scheme of the active part experimental measuring stand [Own creation]

## 5 MEASUREMENT PROCEDURE

Before the experiment was necessary:

- Check the technical condition of the experimental measuring stand and check the connection of each element to match the measurement scheme.
- Connect the temperature sensor **T6**, relative pressure sensor **Pp6** and power consumtioption sensors **Pel** into units „**ADAM**“ which will be connected to a laptop with the evaluation software **ADAM View**.
- Engage electronics and compressor unit with the screw compressor to a electricity power source.
- Shut-off the ball valve **KK4** and the shut-off valve **UV1**.
- The screw compressor will fill all pressure cylinders and pipe system with compressed air to the pressure 6,5 bar (g). This is the maximal pressure on which is setting the valve of maximal pressure.

- Shut-off the ball valve **KK3.**
- Shut-off the drive of compressor unit.
- Open the exhaust ball valve **KK2** and empty the rest of the pipe system and the compressor unit. During this process is the ball valve **KK1** open.
- Last step of preparation was the opening of the ball valve **KK3** with closed the ball valves **KK1** and **KK2**. Thanks this was filled the pipe system with compressed air from the pressure cylinders to the output from the compressor unit concretely to the ball valve **KK1**. Due to the partial expansion of compressed air from the pressure cylinders, occurs the decrease of the air pressure to the value approx. 5 bar (g). This value was measured from the manometers No.: **M1** to **M6.**

The experiment itself was done as follows:

- Data writing was turned on along with the starting of the compressor unit.
- It was now necessary to wait for the compressor operation to stabilize. The temperature in the laboratory increased slowly until a steady state of 21 °C. This temperature fluctuated approximately ± 1 °C during the measurement. The reason for waiting was primarily, the waiting for the warming of an ambient air and the compressor self to the operating state. This was reflected in an increase in power consumption. The power consumption was monitored and once periodicity has been achieved by operation pressure approx. 5 bar (g), the average power consumption value was recorded.
- Each measurement was realized only after the heating of the machine. The compressor unit has always been started as soon as the compressor drive protection has been disabled. It was approx. 30 secounds after the previous shutdown. This has resulted in the most similar operating conditions without appreciable cooling of the compressor.
- Own Shock compression was achieved by filling the pipe system with compressed air to a pressure approx. 5 bar (g) and swiftly openig of the ball valve **KK1** during starting of the compressor unit.
- When the compressor started with a closed ball valve **KK1**, it was possible to monitor the pressure on the pressure gauge on the compressor discharge. When the compressor discharge pressure had reached the desired value, see Table “Tab. 2”, so the ball valve **KK1** opened swiftly. This has led to an imbalance of the pressure ratios and to the Shock compression phenomenon.

The table below shows the combination of pressures which could be realized in the form of experiments in the Laboratory of displacement compressors:

**Tab. 2** The combination of pressures **-** Experiments [4]

| The pressure in the pipe system [bar (g)] | The pressure on the discharge of the compressor [bar (g)] | The intensity of the pressure pulse [bar] | Measurement Duration [s] |
|---|---|---|---|
| 5 | ~0,5 | 4,5 | 72,8 |
| 5 | ~2,5 | 2,5 | 89,7 |
| 5 | ~3 | 2 | 79,4 |
| 5 | ~3,5 | 1,5 | 74,3 |

## 6 SHORT SUMMARY OF RESULTS

This article gives only a basic summary of the facts finding by the experiments without a deeper analysis which will be published in another article.

The Table "Tab. 3" numerically confirms that with increasing of the pressure pulse is occurring, a small but steady increase of the Instantaneous power consumption of a screw compressor drive.

The Figure "Fig. 5" develops measured data to the graphical form. It is obvious here that the increase of the Instantaneous power consumption of a screw compressor drive is increasing with the intensity of pressure pulse. The increase is exponentially but with a very low value of exponent in the equation of a curve – parabola.

The exponential increase confirms the results of the Basic physical model; see The Figure "Fig. 6". The blue part of the diagram "Fig. 6" represents the same curve like is on the diagram "Fig. 5".

**Tab. 3** Summary table [4]

| Intensity of the Pul se [bar] | Lowest Pressure in the system [bar (g)] | Measured Power Consumption [W] | The average Power Consumption measured during 5 [bar (g)] in the system [W] | Measured Power Consumption [%] | Increase of Power Consumption compared with the Average Power consumption [%] |
|---|---|---|---|---|---|
| 1,5 | 5,13 | 5995,4±4,2% | 5912±4,2% | 101,4 | +1,4 |
| 2,0 | 5,17 | 5997,9±4,2% | | 101,5 | +1,5 |
| 2,5 | 5,16 | 6012,7±4,2% | | 101,7 | +1,7 |
| 4,5 | 5,31 | 6020,1±4,2% | | 101,8 | +1,8 |

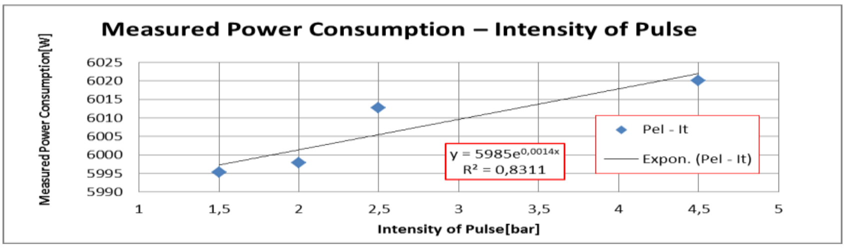


**Fig. 5** The exponential increase of the Instantaneous power consumption of a screw compressor drive by the Shock compression – The experiments [Own creation]

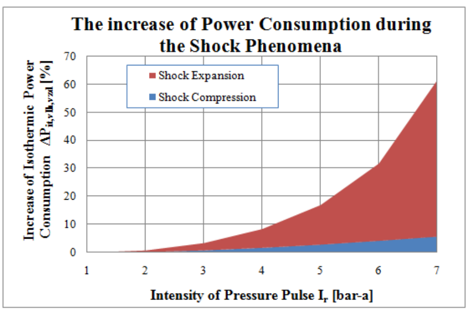


**Fig. 6** The exponential increase of the Instantaneous power consumption of a screw compressor drive by the Shock compression – The Basic physical model [Own creation]

## 8 CONCLUSIONS

This article dealt with the effort of the realisation of the experiment: The measurement of the Shock compression during the operation of the screw compressor. This is the compressor with the rotary movement of the pistons and the Build-in pressure ratio. The experiment was realized on the Experimental measuring stand which was not designed and constructed to the experiment.

It was necessary to design the experiment with using existing equipment.

The experiment was answered at the assumptions and questions from Chapter 2 in the following way:

1. First it was found that the Instantaneous power consumption of a screw compressor drive which reaches the machine during the Shock compression, after balancing of the pressure on the outlet side of the compressor unit with pressure in the pipe system, is higher than the Instantaneous power consumption of a screw compressor drive which is operated during same pressure in a stable state. The result confirms the assumption (Chapter 2, Point 1).
2. In order to verify the results, several sets of measurements were performed for different pressures of the pulses. These measurements were found that by the increase of the pressure pulse intensity (the Shock compression) occurs a gradual increase of the Instantaneous power consumption of a screw compressor drive. This increase is not linear, as it appears at first glance from the graph above in the Figure "Fig. 5" but it is a very slowly growing the Parabola. This, on the one hand, corresponds to the assumption based on available technical literature (Chapter 2, Point 2) and it also corresponds to previous calculations.
3. As mentioned in the previous Chapter 6 so a detailed analysis of the measured data will be made and published in another article. This point therefore remains open. However, the preliminary conclusions were also presented in this article. As far as possible, theories and calculations were verified using a practical experiment.
4. The last point from Chapter 2 was to test the technical possibilities of the existing Experimental measuring stand which is located in the Laboratory of displacement compressors, in terms of measurements non-standard operation states of the compressors. Evaluate usability and status of existing gauges and propose important points that should not be overlooked when will be designed the new Experimental measuring stand. It had been found that the present equipment is applicable for measuring these phenomena but this application is not ideal in any case. The biggest problem is the manual initiation of Shock compression using the KK1 ball valve. Manual control introduces an error element into experiments which can not be eliminated. It is only possible to try to reduce this error by using a large number of repeated measurements and obtaining a large amount of measured data. This method has also been used in this case. Generally, this is not a good method for two reasons. There is considerable time-consuming measurement and frequent starting of the machine reduces the service life of the compressor unit drive. The frequent start of the drive is the warming up of the electromotor and overloads the electrical network by the initial current shock. And it can lead up to damage of the electromotor or electrical network failure. This and other findings should be taken into consideration for the possible future realization of the new experimental measuring stand.

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