Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

LABORATORY STAND FOR INVESTIGATIONS OF THE QUICK-CHANGING TEMPERATURE OF GAS FLOWING IN THE PISTON COMPRESSOR OUTLET CHANNEL

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Abstract

This paper presents a laboratory stand, created as a part of work on the doctor dissertation, intended for investigation of heat and flow processes taking place in the Espholin H3S piston compressor outlet channel. The test stand elements and their configuration within the stand are described. Discussed are also problems connected with the quick-changing measurement technique, solutions which have been proposed so far in that technology and premises are determined of choosing most suitable methods for measuring quick-changing temperature of outlet gases in piston machines as a diagnostic parameter.

Key words: *piston compressor, heat and flow processes, gas temperature measurement, diagnostics.*

1. Introduction

Planned investigations of heat and flow processes in the outlet channel of an air compressor are directed at diagnostic problems. Their main purpose is developing a methodology of evaluation of the technical state of elements bounding the working spaces of a compressor, based on the state parameters of thermodynamic medium observed in an outlet channel with adequate measurement instrumentation. For realization of a so formulated research objective it is necessary to build and to outfit a laboratory test bed allowing experimental tests to be carried out in the conditions as close as possible to the operating conditions of the real object. Measurements of the quick-changing pressures and temperatures of outlet gases [1, 4, 5], which were carried out on engines and piston compressors, allow to isolate several important metrological problems, which are to be taken into account in planning experimental tests both on a laboratory stand and in real object diagnostics. The most important of them are considerable inertia of the temperature sensors and the influence of external conditions on the obtained measurement result. However, proper selection of adequate measurement methods and instrumentation allows to minimize most of the shortcomings connected with measurements of quick-changing temperatures.

2. Diagnostics of piston compressors

Piston compressors are widely used aboard ships, first of all for compression of the following gases [6]:

- air, mainly for:
  - starting main and auxiliary engines,
  - driving the mechanism of propeller pitch change,
  - driving the main engine disengaging couplings and reversing mechanisms,
  - scavenge of kingston valves, pipelines and other water spaces,
  - scavenge of fire extinguishing installations,
  - ship horn (tyfon),
  - fuel atomization in boiler furnaces,
  - starting the turbine combustion engines – the fuel atomization, ignition and combustion process assist,
  - working medium in the pneumatic control systems,
  - household applications (e.g. hydrophores).
- refrigerating media (in refrigerating and air conditioning installations).

Therefore, a very important operational feature is diagnosis of that equipment without interference into its internal structure. One of the essential methods is parametric diagnosing based on the measurements and comparative analysis of static temperature at the end of gas compression. In the case of stabilized processes, that parameter allows to obtain such information, among others, as:

- indicating places where the greatest energy losses occur,
- defining the type of energy process disturbances in a compressor,
- identification and location of defects of compressor working space structural subassemblies and elements.

During compressor operation it is possible to watch many diagnostic symptoms indicating disturbances, e.g. decreased output and rotational speed, knocks in the mechanical system, smoke, too low lubricating oil pressure at the oil pump outlet [2]. Some of the mentioned compressor disfunctions may cause also an increase of temperature at the end of the compression process.

The most often occurring causes of compressor output decrease are the following:

- fouled air filter, which causes decreased pressure of the air suction (and in addition increased end temperature of compression) as well as reduced flow throuput in the pumping valve due to difficult to remove deposits of charred oil (as an additional consequence of the increased end temperature of compression),
- increased temperature at the end of air compression, considerably higher than the calculation value (due to lowered cooling effectiveness and too high cooling water temperature, caused e.g. by deposits of limestone on the cooling space walls).

In view of frequent occurrences of various nonoperational conditions in the use of compressors, it is necessary to develop diagnostic methods allowing to detect them early and to remove their initial causes [3]. It will make possible to apply a technical service planning strategy in accordance with the equipment actual technical condition and therefore will increase durability and reliability with considerable reduction of the service labour consumption.

In developing an optimum diagnostic method, proper methodical questions should be formulated regarding the way the diagnostic tests should be carried out:

1. What parameters and where to measure them?
2. In what way and when to be measured?
3. What equipment and measurement technologies to be applied?

4. How to draw the conclusions?
5. Which of the selected diagnostic parameters brings most diagnostic information and simultaneously is easy to measure?

Then, by means of proper methods of diagnosing (a.o. experimental tests with the use of diagnosing systems and numerical simulation of heat flow processes), the questions should be answered in such a way that by interpretation of the obtained diagnostic test results relations can be found between the received values of diagnostic parameters (symptoms) and known recognizable inaptitude states most often occurring in a piston compressor operation process.

3. Object of investigation

In order to obtain diagnostic information about the technical condition of structural elements confining the working spaces of an air compressor, a laboratory stand has been set up including the following subassemblies: an electric motor driven Espholin H3S type air compressor, an air tank and a piping system. The whole installation is mounted on a shock-absorbing foundation. Additionally, standard measurement instruments: manometer, thermometer and thermocouple are installed and also safety-valves protecting the compressed air-filled pressure system against exceeding the admissible pressure, which increases safety of the stand operation. This test stand will provide facilities for verification of the developed mathematical models of heat-flow processes in the whole compressor system, with a possibility of using them also in the combustion engine diagnostics.

Main subassembly in the stand is a two-stage Espholin H3S piston air compressor with interstage cooler, of the following dimensions:

- stage I – piston diameter D=95 mm, piston stroke S=80.1 mm (±0.1);
- stage II – piston diameter D=50 mm, piston stroke S=80.1 mm (±0.1).

Main operating parameters of the compressor are shown in Table 1.

Table 1. Main operating parameters of the Espholin H3S air compressor

PARAMETER	VALUE
Rotational speed	750 min^{-1}
Volumetric output	425 dm^3/min
Effective output	305 dm^3/min
Power	5.5 kW
Internal thread on the output side	0.5”

The Espholin H3S compressor is driven (through belt transmission) by an electric motor of 5.0 kW power at 1460 min^{-1} rotational speed and 6.0 kW power at 1755 min^{-1} speed. Fig. 1 shows general view of the Espholin H3S piston compressor assembly during initial stage of building the test stand.

Fig. 1. General view of the Espholin H3S piston compressor assembly before mounting on the foundation

In the discussed compressor system a pressure tank (with 15 bar working pressure) of 120 dm^3 capacity is mounted as a compressed air accumulator. Fig. 2 presents the pressure tank valve head with the inlet and outlet stub pipes. Fig. 3 and 4 present general view and schematic diagram of the test stand.

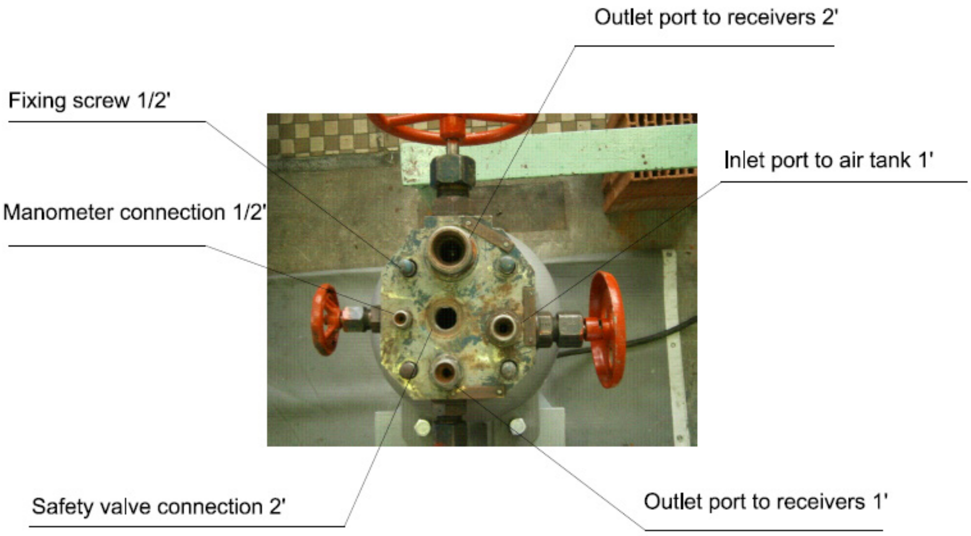

Fig. 2, Pressure tank valve head

Air temperature measurements in the test stand compressor outlet channel are carried out with a K type T-201p-K-0,5-20-1,5-1-M6-1-S-6-200 thermocouple, its technical parameters given in Table 2.

Table 2. Technical parameters of the temperature gauge

Temperature gauge	K type, class 1
Gauge diameter	d=0.5 mm
Gauge length	L_c=20 mm
Casing material	Inconel 600 (72% nickel and 14 - 17% chromium alloy)
Conductor length	$L_p=1.5 \cdot 10^3$ mm
Conductor insulation	glass fibre x 2/ braided screen
Process terminal type	M6 thread
Execution	small spring, penetration weld
Work temperature	up to 200°C

Time-constant	$8 \cdot 10^{-3}$ s

Fig. 3. General view of the Espholin H3S piston compressor test stand

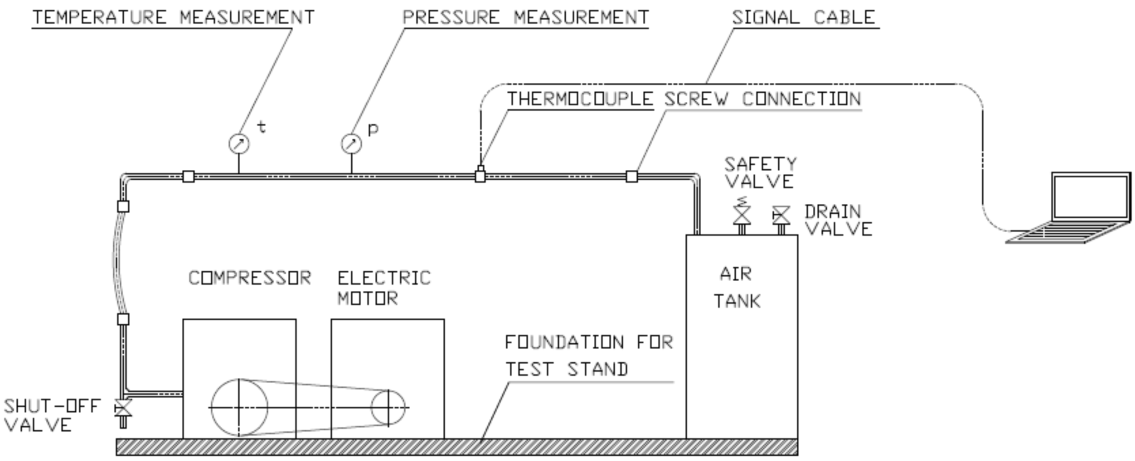

Fig. 4. Schematic diagram of the Espholin H3S piston compressor test stand

The test stand (Fig. 3 and 4) will be used for performing the following research tasks:

- investigation of the heat-flow processes in a piston type air compressor,
- the stand can be easily adapted, depending on the needs, for application of different measurement techniques and tools (replaceable measurement section),
- possibility to introduce, into the compressor and the connected network, virtual (simulated) operational inaptitude states (e.g. simulation of the piston ring wear by ”undercuttings”, flow throttling with an orifice),
- didactic purposes.

4. Measurement problems

Many methodological problems may be encountered during gas quick-changing temperature measurements from the side of temperature gauge or measurement signal converter and also from disturbances caused by the measurement stand environment. In order to develop an effective method of impulse-diagnosing of a heat-flow system, method based on temperature measurements of gas flowing with high velocity, the influence of measurement disturbing factors should be analysed and ways of minimizing their impact should be worked out.

One of the basic disturbances significantly influencing the accuracy of gas temperature measurement results is inertia of the applied gauge. The most often used in this kind of measurements are K type thermocouples (chromel-alumel), manufactured in broad range of the measuring element lengths and diameters and also in versions with or without casing. In order to reduce the measurement inertia to a minimum, the thinnest possible measuring element should be used, but due attention has to be paid to its less durability and resistance to defects (these features appear additional problems in this measurement method) with decreasing diameter. Gauge without the measuring element casing is much less durable, but also has less inertia. Thermocouple is a solution matching both aspects, its weld penetrates the casing material (Fig.5), which reduces the measurement inertia and maintains considerably greater durability. An effective solution is to use a thermocouple with its measurement terminal sticking 1-1.5 mm out of casing.

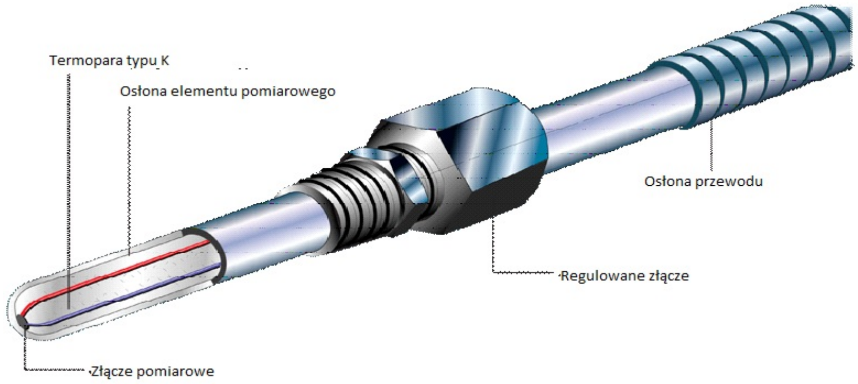

Fig. 5. Schematic view of cased thermoelement

The determining parameter of thermocouple inertia is its time-constant, dependent on the thermocouple mechanical structure and size, thermophysical properties of the material used as well as thermodynamic aspects and character of the gas flow. Figure 6 presents graphical interpretation of the thermocouple time-constant. Jn spite of the time-constant value being determined by measurement element manufacturers, calibration of gauges appears necessary. The most up-to-date method of calibration is the constant-point method, based on the use of phase transitions (melting, solidification, triple point) of fine metals and water. Calibrated temperature gauges are placed in heated or cooled cells filled with fine metals. Thanks to a precise control system, the created phase transition state can be kept for several or some scores of hours, maintaining constant material temperture. Calibration by the constant-point method may be carried out in:

- Mercury triple point, Hg (-38.8344 °C),
- Water triple point, H_2O (0.01 °C),
- Galium melting point, Ga (29.7646 °C),
- Zinc solidification point, Zn (419.527 °C),
- Aluminium solidification point, Al (660.323 °C),
- Copper solidification point, Cu (1084.62 °C),
- Palladium melting point, Pd (1553.5 °C) by wire method.

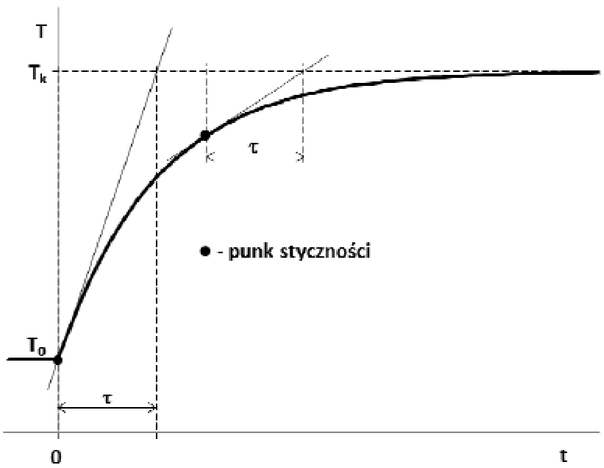

Fig. 6. Graphical interpretation of thermocouple time-constant, where: τ – time-constant, k – point of tangency, T_0 – ambient temperature at time τ=0, T_k – measured medium temperature, t – time

An important factor influencing the accuracy of quick-changing temperature measurements is the way of gauge mounting. Main obstacle is thermocouple heating from the material of heat channel (or other supporting element) where it is screwed or soldered in during the measurement. This has a decisive impact on the measurement results. The only method of preventing or significantly reducing such disturbance is efficient insulation of the gauge, e.g. by applying a water-cooled shield (Fig. 7). However, this is connected with possible leakage and water penetration to the flow channel.

Fig. 7. Water cooled type K thermocouple

5. Existing measurement conceptions

Combination of the two-way correction method and the recovery coefficient determination method is presented as a solution of the problem of measurement of time-dependent gas temperature in a broad input function frequency range. In effect, a dynamic-error-free temperature signal is obtained, resolved into components corresponding to the static temperature (resulting from the medium thermodynamic parameter changes) and dynamic temperature (connected with the gas flow velocity) [5].

Essence of the method proposed by the Author of the above quoted publication is using two transducers of different (unknown in advance) dynamics, measuring the same input signal. The Author proposes a special design Prandtl probe to be used. Apart from the classic measurement of total and static pressure, that probe ensures gas static temperature measurement (no dynamic component of temperature has an influence on the thermocouple indications). The measurement is carried out by means of a miniature thermocouple placed at the point corresponding to the static pressure measurement (on the probe gauging tip perimeter) and thermally insulated from the probe [5].

Other Authors [1] developed a solution based also on quick-changing temperature measurements by means of two thermoelements of different diameters, made from a material with good conductivity and low thermal inertia (proposed by H. Pfriem in 1936). The difference in comparison with the above described method consists mainly in building a test stand with specially prepared disc, in which were placed two thermocouples of different diameters and an anemometer to perform measurements of gas parameters in identical instantaneous conditions.

6. Evaluation of the proposed methods

Aspiring to setting up an own test stand, and in consequence to developing a measurement method of flowing gas quick-changing temperature, one should evaluate the existing conceptions, taking into account several aspects:

1. technical capability of carrying out the measurement (adapting an existing measurement system to the required measurement conditions),
2. appropriateness of the stand for planned research (type and method of performed measurements),
3. costs of the measurement instrumentation.

After analysis of the above mentioned aspects, a most effective method should be proposed for realization of the planned programme of investigations to be performed on the built laboratory stand, the method allowing to minimize most of difficulties occurring during quick-changing temperature measurements, with simultaneous simplicity and integrity of the stand structure and relatively low investment costs. The proposed solution should also be applicable to temperature measurements on other similar stands (e.g. combustion engines), and particularly to carrying out diagnostic investigations on real objects.

7. Summary

The thermodynamic medium temperature may provide diagnostic information on the technical state of structural elements bounding the piston machine (mainly compressors, but also combustion enegines) working spaces. This is connected with necessary measurements of the flowing gas quick-changing temperatures and their conception is an important subject of the contemporary metrology (thermometry). In order to develop an innovative, but at the same time based on the existing solutions, method of measuring that diagnostic parameter, a "golden mean" must be proposed meeting the requirements of high accuracy of measurements (which determines the reliability of diagnosing), and relative simplicity and economy of the method. Therefore, the most suitable solution for temperature measurements of quick-changing heat-flow processes, taking place in a piston compressor outlet channel, seems to be a method based on measurement of quick-changing temperatures by means of two thermoelements with different diameters and with water-cooled insulation screen.

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