

## Leakage diagnostics in pneumatic systems using transient patterns

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### Abstract

Pneumatic cylinder leakage on-line diagnostics is considered in the paper. Flow and pressure transient patterns were recorded given various combinations of simulated leakage, working pressure and actuator load mass in the assembled testing bench. Search of diagnostic features applicable for leakage detection and estimation was performed among parameters of acquired data. Data-driven models were proposed for leakage detection and estimation irrespective of varying working conditions.

**Key words:** pneumatics diagnostics, leakages estimation, condition monitoring.

### Introduction

Pneumatic actuators are widely used in automated industrial processes. Their technical conditions monitoring is one of measures towards implementation of predictive maintenance in a plant. As a result of long term operation connecting tubes, piston sealings and internal surfaces of a pneumatic actuator (in our study – pneumatic cylinder) wear out. This causes change of actuator speed, force and air consumption. All this together is regarded as performance.

Manufacturers of pneumatic components usually specify number of operation cycles, after which it is recommended to replace the component or its sealings. However, in every particular installation and working conditions leakages may appear and progress very specifically. Therefore, a diagnostic system capable of on-line monitoring of pneumatic actuator performance could be very valuable. Term “on-line” here refers to the monitoring mode without process line disassembly or stop and without introduction of special testing modes.

In our study we set a goal to investigate possibilities of implementing diagnostic system for actuator leakages detection and estimation. Some works in this field has already been published [1-5]. Most of these papers are concerned with application of static and timing process parameters. Since pneumatic actuator usually operates in a switching manner we step forward to search for applicable diagnostic features in the patterns of air flow and pressure transient processes. Transient process of air flow and pressure can be acquired using common industrial process transducers.

### Approach of building data-driven diagnostic models

By the diagnostic model we denote relationship between set of directly measured process parameters and quantity describing fault, i.e. leakage. It is possible to measure patterns of air flow in the supply line and pressure at different points directly. All the patterns constitute set of features  $D_1, D_2, \dots, D_n$  carrying information about the leakages in the cylinder. In the paper we consider three types of leakages [6]:

1. Cylinder extend line leakage;
2. Cylinder retract line leakage;
3. Cylinder piston sealing leakage.

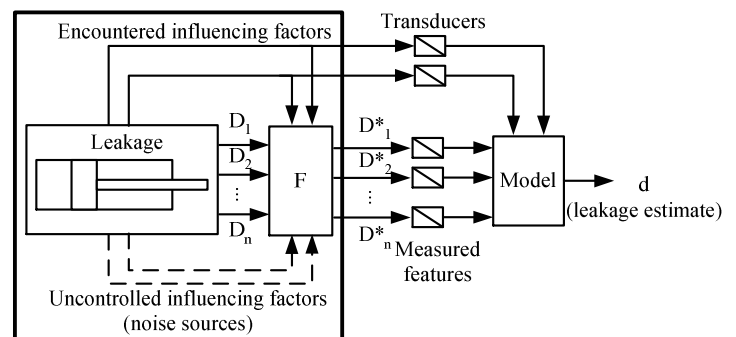


Fig. 1. Leakage diagnostics scheme

Diagnostic features are influenced by the working conditions of pneumatic system: working pressure, actuator load, throttle settings, tubing length, fluid temperature, etc. Thus, in fact one is only able to measure features  $D_1^*, D_2^*, \dots, D_n^*$ , that to some extent reflect not only leakage level but also set of working conditions parameters. Some of influencing factors can be measured directly, e.g. working pressure, but some can not, e.g. load mass. Therefore, diagnostic model must be built utilizing features  $D_1^*, D_2^*, \dots, D_n^*$  and encounter measured influencing factors (see Fig. 1). The effect of factors falling in to the group of uncontrolled, e.g. load mass, we treat as source of random noise.

Diagnostic model in principal could be derived by solving nonlinear differential equations describing operation of pneumatic system [7]. However, it is mathematically difficult to solve these equations, and they contain constants whose real values are seldom known in practice (dynamic and static friction coefficients, hydraulic friction coefficient, etc.) [8]. Therefore, we chose a data-driven model building based on learning. To generate data for data-driven model building typical pneumatic system (testing bench) “cylinder-control valve” was assembled.

In this investigation we assume tubing lengths and throttle settings are constant. Thus, the model will be

adapted to the setup of pneumatic system by providing it with training data, acquired from real operating testing bench.

**Experimental setup and data collection**

Scheme of developed testing bench is shown in Fig. 2. Standard pneumatic cylinder with 80 mm stroke length and 32 mm piston diameter was used.

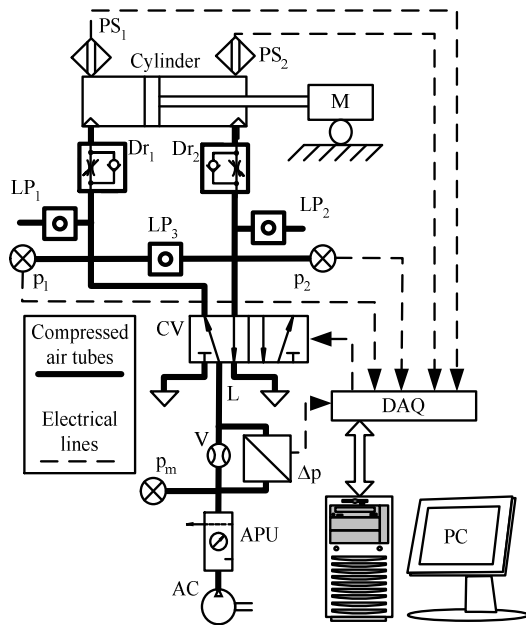


Fig. 2. Setup of testing bench

The testing bench consists of a pneumatic cylinder, control valve CV, one-way throttles Dr<sub>1</sub> and Dr<sub>2</sub>, proximity switches PS<sub>1</sub> and PS<sub>2</sub>, working pressure p<sub>m</sub>, first and second cylinder chamber pressure p<sub>1</sub> and p<sub>2</sub> transducers, Venturi nozzle V, differential pressure Δp transducer, load mass M, air preparation unit APU, air compressor AC, computer PC with data acquisition board DAQ installed.

Patterns of flow Q(t) (calculated from Δp(t) patterns) and pressures p<sub>m</sub>(t), p<sub>1</sub>(t) and p<sub>2</sub>(t) were acquired together with valve control and proximity switches signals given all possible combinations of influencing factors and simulated leakage levels. Altered influencing factors were working pressure p<sub>m</sub>=0.40, 0.45, 0.50 MPa and load mass M=0, 1, 2, 3, 4, 5 kg. Leakages were simulated using orifices of circular shape and known diameters: d<sub>0</sub> = 0.0 mm (no leakage), d<sub>3</sub> = 0.3 mm, d<sub>5</sub> = 0.5 mm and d<sub>7</sub> = 0.7 mm. They were introduced in the following places of the pneumatic system:

- leakage from the tube of first cylinder chamber to ambience – LP<sub>1</sub> (extend line leakage);
- leakage from the tube of second cylinder chamber to ambience – LP<sub>2</sub> (retract line leakage);
- leakage between cylinder chambers (through piston sealings)– LP<sub>3</sub> (piston sealing leakage).

**Building diagnostic models**

All acquired data were searched for features sensitive to leakage but invariant to influencing factors. Conducted investigation revealed two promising features for piston leakage diagnostics that can be extracted from flow pattern (Fig.3):

1. Magnitude A of initial cylinder operation phase [7]. It turned out to be insensitive to load mass.
2. Compressed air consumption S, calculated as integral under flow pattern in the fixed time interval T<sub>1</sub> to T<sub>2</sub>. Here T<sub>1</sub> corresponds to the moment of control valve signaling, T<sub>2</sub> was chosen experimentally.

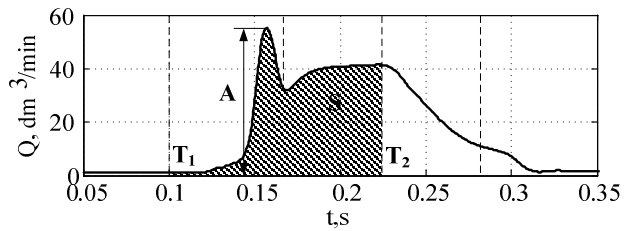


Fig. 3. Selected diagnostic features: air flow amplitude A and compressed air consumption S

In a diagnostic system leakage (fault) may be characterized either by:

- 1) feature reflecting size of leakage and independent to influencing factors;
- 2) parameter directly characterizing fault, e.g. effective diameter of leakage orifice.

In the first case change of diagnostic feature A could be employed. Since A is dependant upon working pressure p<sub>m</sub> that in real systems does not fluctuate in a wide range, it was assumed that dependence could be approximated using linear equation

$$A_0 = \alpha_0 + \alpha_1 p_m,$$

here coefficients a<sub>0</sub>, a<sub>1</sub> are determined by linear regression analysis provided learning data generated at different levels of working pressure and fault-free (no leakages) conditions. Any appeared change

$$\Delta A = A_0 - A_m$$

we attribute to the occurrence of piston leakage. Here A<sub>m</sub> denotes value observed during monitoring. Variations of load mass M were treated like presence of random noise (see Fig.4). Indeed, scatter of values shown in the Fig.4 was due to load mass changes given fixed p<sub>m</sub>. We can see, that increase of leakage LP<sub>3</sub> causes decrease of A which respectively means increase of ΔA. Influence of working pressure p<sub>m</sub> upon A<sub>0</sub> is obvious but its influence upon ΔA is eliminated.

The second approach when leakage is characterized using effective diameter d is represented in the Fig. 5. To build a diagnostic model air consumption S change ΔS=S<sub>0</sub>-S<sub>m</sub> in respect to air consumption reference S<sub>0</sub> was estimated, setting all possible combinations of d=0.0, 0.3, 0.5, 0.7 mm, M=0 ... 5 kg and p<sub>m</sub>=0.40, 0.45 MPa.

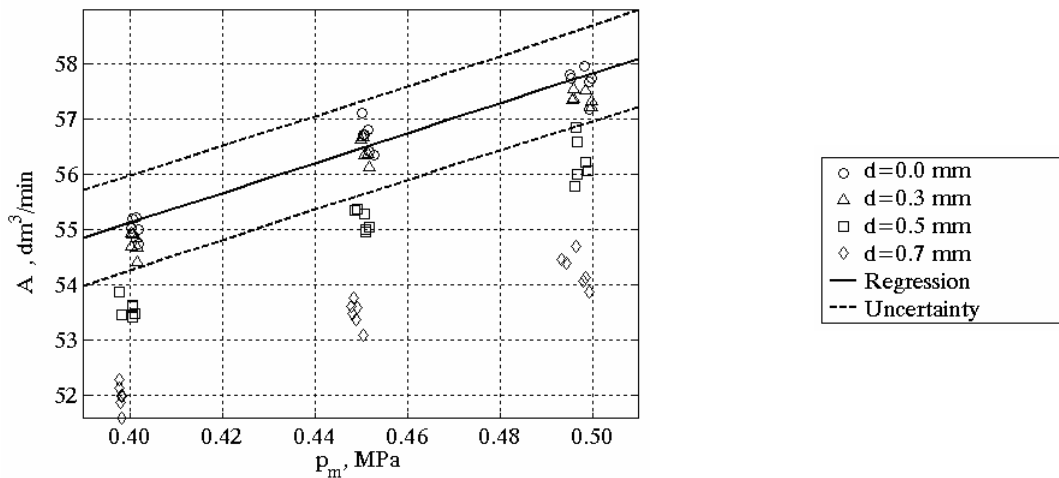


Fig. 4. Dependence of feature A upon working pressure  $p_m$  and piston sealing leakage

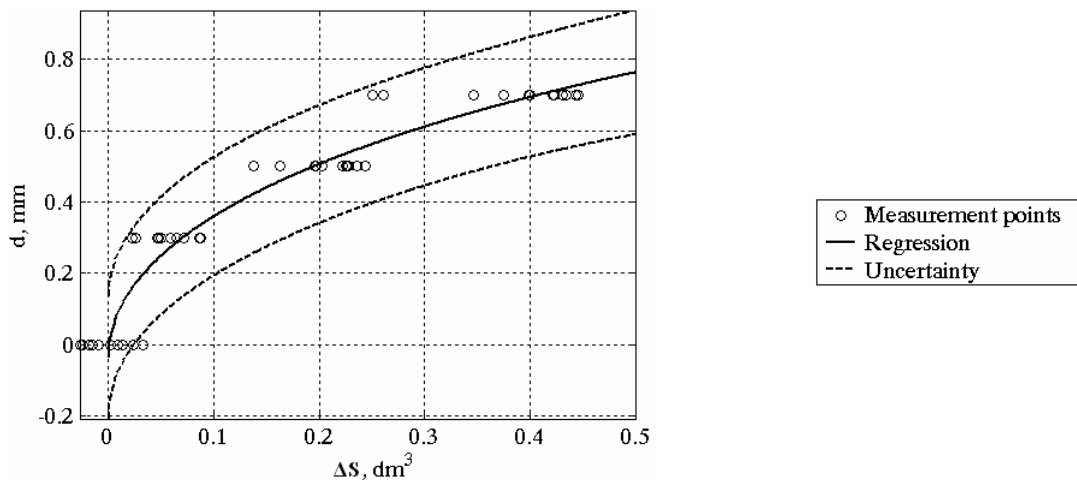


Fig. 5. Dependence of increment of air consumption  $\Delta S$  upon leakage  $LP_3$  level

Observing the data scatter plot (Fig. 5) the assumption was made about quadratic dependence

$$d = b_0 + b_1 \Delta S + b_2 \sqrt{\Delta S} .$$

Its coefficients were estimated using multiple regression analysis. Changes of  $p_m$  and  $M$  were attributed to the uncontrolled disturbances.

Leakages  $LP_1$ ,  $LP_2$  and  $LP_3$  can be distinguished comparing diagnostic features in retract and extend subcycles [6]. It was found that diagnostic features  $\Delta A$  and  $\Delta S$  are affected: 1) during extend subcycle in case of  $LP_1$  leakage; 2) during retract subcycle in case of  $LP_2$  leakage; 3) during both subcycles in case of piston leakage  $LP_3$ .

Conditions with more than one simultaneous leakage have not been analyzed yet.

## Conclusions

1. Pneumatic actuators diagnostic method utilizing dynamic air flow characteristics was proposed and analyzed. It enables online piston, extend line and retract

line leakage level estimation and leaking unit identification in the pneumatic system.

2. Dynamic air flow pattern magnitude and air consumption over constant time interval were found to be most suitable diagnostic features for pneumatic cylinder piston, extend and retract line leakage estimation. Corresponding models utilizing these features were composed based on experimental data.

3. It was found that leakage appearing in the different places of pneumatic system affect the parameters of flow transients specifically. This could be used to identify system unit with leakage.

## References

1. Tasic Z., Stojiljkovic M., Stojiljkovic D., Blagojevic D. Application of the multiple-valued logic to detecting irregular states in the electro-pneumatic systems, Mechanical engineering. 1998. Vol. 1. Nr. 5. P. 573 – 580.
2. Nogami T., Yokoi Y., Kasai M., Kawai K., Takaura K. Failure diagnosis system on pneumatic control valves by neural network. IEEE International Conference on Neural Networks. 1993. Vol. 3. P.1876-1881.

3. **Gomes de Freitas J. F., MacLeod I. M., Maltz J. S.** Neural networks for pneumatic actuator fault detection. Transactions of the South African Institute of Electrical Engineers. March 1999. Vol. 90. No.1. P. 28-34.
4. **Karpenko M., Sepehri N.** Neural network classifiers applied to condition monitoring of a pneumatic process valve actuator. Engineering applications of artificial intelligence. 2002. No.15. P.273-283.
5. **Evans D. S., Underwood P.** Self-diagnostics in pneumatic systems using programmable logic controllers. Mechatronics. The Basis for New Industrial Development. 1994. P.481-486.
6. **Kaškonas P., Nakutis Ž.** Pneumatinio cilindro vidinio nuotėkio įvertinimo galimybių tyrimas. Matavimai. 2005. Nr. 1(33). P.22–27.
7. **Kaškonas P., Nakutis Ž., Žiedelis S.** Teorinis priklausomybių tarp pneumatinių cilindrų diagnostinių ir būklės parametrų tyrimas. Matavimai. 2002. Nr. 3(23). P.25–29.
8. **Grahl-Madsen M.** Computerized analysis of a pneumatic actuator, division of thermal energy and hydro power. Norwegian institute of science and technology, SIM'S 1996, Trondheim, Norway.

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