DAMAGE IDENTIFICATION OF PNEUMATIC COMPONENTS BY ACOUSTIC EMISSION

Houssam MAHMOUD1, Frantisek VLASIC2, Pavel MAZAL1, Miroslav JANA3,

1 Brno University of Technology, Brno, Czech Republic
2 Center of Technical Diagnostic ZD Rpety - DAKEL, Czech Republic
3 Policske strojirny a.s., Policka, Czech Republic

mahmoud@fme.vutbr.cz, mazal@fme.vutbr.cz, mjana@pos.cz, vlasic@dakel.cz

Abstract:
The main aim of this paper is to find a typical acoustic emission signal associated with a particular type of damage in the cylinder. Currently, condition monitoring of the pneumatic systems are mainly based on vibration monitoring, ultrasound principle and noise analysis of the equipment. However, the capabilities of these methods are insufficient, less sensitive and unreliable. The acoustic emission signals, are obtained from the undamaged cylinders, were processed and analysed, after that the same cylinders were damaged with different type of defects. A new parameter "\(D_{AE}\)”, which was developed, evaluates and classifies the level of damage detection on the basis of the recorded differences between the undamaged and damaged cylinder. An evaluation of the cylinder cycling during idle motion is a part of the results. This study follows previous papers focused on the development of a new system for condition monitoring of pneumatic components supported by the Technology Agency of the Czech Republic.

Keywords: condition monitoring, pneumatic cylinder, damage, acoustic emission

1. Introduction

Non-destructive testing is used to detect, locate, measure, evaluate flaws; assess integrity, properties, and composition; and measure geometric characteristics [1]. Various NDT technologies, such as ultrasonic-based methods, radiographic methods, dynamic methods, acoustic emission (AE) techniques, and acoustic-ultrasonic (AU) techniques have been studied. Each NDT technique has both advantages and disadvantages with regard to cost, speed, accuracy, and safety [2].

AE, a type of non-destructive testing, is used to monitor integrity and to characterize the behaviour of materials when they undergo deformation, fracture. Unlike ultrasonic or radiographic techniques, AE does not require external energy; but it is an elastic stress waves generated by the energy released when microstructural changes [3]. These waves are sometimes sufficient amplitude to be detected by sensors attached to the surface; the sensors convert the mechanical disturbance to a voltage-time waveform [4]. To monitoring components during manufacturing, detecting and locating leaks, mechanical property, and pressurized vessels [5].

Pneumatic components represent an important part of many technical devices in transportation, mechanical, automotive and power engineering etc. [6]. Pneumatic actuator is a device which transform the energy from a compressed air supply into a rotary or linear movement. Actuators provide specific tasks such as clamping, picking and placing, filling, ejecting and tool changing [7]. If the speed of moving objects is not critical, pneumatic systems are considered cheap, clean, and easy to maintain alternative for the automation [8].

AE technique relies on the fact that escaping gas or liquid through a small breach creates a high frequency sound wave that travels through the enveloping system [9]. The relation was described between amplitude of AE signal and the rate of gas leak in a valve at the frequency...
domain, and measurement of noise from gas valve. The ability of AE to monitor pneumatic cylinders was proved [10]. Investigating possibilities of implementing AE system for pneumatic cylinder leakages detection. The research of influence of leakage rate was performed on RMS value of AE signal, using sensors of AE while applying various internal pressures [11].

Coefficient of Detection is derived from the use of non-destructive diagnostic methods. Scale of detection in the range of 1 to 10, where 1 is the fault certainly detected and at 10 you cannot discover by NDT, was taken from the table FMEA (Failure Mode and Effects Analysis), which classifies the degree of detection "D" for standard control method. The coefficient "S" severity of the particular defect. This parameter is given in two modifications, namely "S1" for a single defect without sequelae and "S2" reflecting the worst possible consequences, which may indicate a defect [12].

2. Experimental

2.1 Assembly of experimental equipment

The goal is to create a new diagnostic procedure for checking the function of pneumatic cylinders using AE. The records of AE signal from intact pneumatic cylinders and similar series from cylinders containing with different type of artificial defects were compared. Three types of cylinders were tested - PS, PB and RD (producer Policske strojirny a.s.), see Figure 1.

At Brno University of Technology, there are in the lab the experiment platform, test devices and some equipment including damaged and intact cylinders, AE sensors were installed on different positions of the body, air pressure supply, the pneumatic control system, the linear potentiometer and the AE monitoring system by analyser DAKEL - IPL. An executive scheme for the connection of components and experiment is shown in Figure 2.

2.2 Different type of artificial defects

- Leakage
- Leaks in motion
- Galling
- Mechanical defects
2.2.1 Leakage

Leakage is caused by deterioration or loss of sealing function, damage of the seals surfaces of the components or through the part. There are two type of leaks. Leaks in the end position when the pressure above the piston / retracted piston rod (TP). Leaks in the end position at a pressure below the piston / rod out (BP).

![Leakage Diagram](image)

Figure 3. Leaks below the piston in the end position [12]  
Figure 4. Leaks in the end position when the pressure above the piston [12]

2.2.2 Leaks in motion

When movement is moreover capable mentioned leak galling control when damping is in operation, before reaching the end position. Leaks damping when ejecting rod (VP). Leaks shock when inserting the rod (ZP).

2.2.3 Galling (G)

The causes of the deterioration of friction conditions can be lubricant degradation, foreign bodies, mixed with grease particles arising wear etc.

2.2.4 Mechanical defects (M)

Among mechanical defects can include damage of parts from an external force, the loss of thread connection with their subsequent to release parts and high cycle fatigue damage. Damage from the external force, which may not be visible from outside as bending rod which can cause irregularities in operation of certain sections of the stroke of the cylinder or even blocked. Loosening of bolted joints, damage of caps, can exhaust the cylinder with the destruction of the above-mentioned serious consequences indications such as disorders at an early stage can significantly contribute to the prevention of serious accidents.

![Mechanical Defects Diagram](image)

Figure 5. Mechanical defects [12]
3. Results and discussions

AE Signals from undamaged and damaged cylinders were compared. Range of measuring frequencies of signal are approximately from 50 kHz to 400 kHz, according to the damages of cylinders, some dominant frequencies of AE signal were lost or gained. The graphs show that AE sensor detects signal only if the position is before and in ejected mode, i.e. top dead centre (TDC) and bottom dead centre (BDC).

The analysis of the frequency spectrum represented, and the frequency of the signal change over time depending on the type of damage and the number of completed cycles.

Figure 6 (a) shows the signal envelope of initial run of cylinder No. 14, the Figure 6 (b) and (c) show the normal run of cylinder No. 14, and (d) shows the artificial mechanical damage of cylinder "Loosening 4 screws under the piston". All graphs in Figure 6 were compared, the shape of signal envelope is same in (a), (b), (c) and in (d) is different. The amplitude of (a) is higher than (b) and (c) due to the initial running of cylinder No. 14, but in (d) is twice as high as normal running. When repeated measurements intact cylinders and damaged cylinders were recorded almost identical results.

![Figure 6. Signal envelope of cylinder No. 14 in different conditions](image-url)
The Figures 7 and 8 show the signal spectrum of intact and damaged cylinder No. 12 and 4. The amplitude spectrum and bandwidth of both cylinders in (b) is bigger than (a) during determined time.

![Figure 7. Signal spectrum of cylinder No. 12](image)

(a) Intact cylinder  
(b) Damaged cylinder

![Figure 8. Signal spectrum of cylinder No. 4](image)

(a) Intact cylinder  
(b) Damaged cylinder

The basic criterion of the analysed signal is bandwidth "BW", the amplitude spectrum "A" and the incidence of new (dominant) frequency in the spectrum due to the damage. Based on these indicators, a new parameter "D_{AE}", was developed, assesses and classifies the level of detection (damage) based on the identified differences between the above-mentioned criteria undamaged and damaged cylinder.

There are always three basic characteristics specified bandwidth - BW1 (A1max to 100 kHz), BW2 (A2max to 280 kHz) and BW3 (A3max to 360 kHz) and sizes amplitude spectrum. Bandwidth for all test undamaged cylinders ranged from 50 to 120 kHz (BW1), 270 to 310 kHz (BW2) and 340 to 370 kHz (BW3).

Table 1 provides some types of artificial defects of cylinders and assessment of changes in the monitored parameters of cylinders and constitutes a significant factor D_{AE}. The changes (percentage) were registered in cylinders No. 4, 12 and 14, of which were most pronounced.
Table 1. The coefficient of detection "$D_{AE}$" for cylinders

<table>
<thead>
<tr>
<th>No. Cylinder</th>
<th>Type of defect</th>
<th>Description of the defect</th>
<th>Change BW (%)</th>
<th>Amplitude change (%)</th>
<th>The average change (%)</th>
<th>S1</th>
<th>S2</th>
<th>D</th>
<th>$D_{AE}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>BP 03</td>
<td>Missing O-ring on the piston rod</td>
<td>50</td>
<td>66</td>
<td>58</td>
<td>3</td>
<td>10</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>BP 04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>TP 07</td>
<td>Cutting the O-ring on the piston rod</td>
<td>72</td>
<td>133</td>
<td>102</td>
<td>3</td>
<td>10</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>TP 08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>M 03</td>
<td>Loosening 4 screws under the piston</td>
<td>16</td>
<td>33</td>
<td>24</td>
<td>3</td>
<td>10</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

Graphical representation of the most important parameters of the Table 1 is shown in Fig. 9. This graph shows that the method provides reliable detection AE damage than existing control methods. Changes in the parameters of damage "BW", "A" and the coefficient of detection "$D_{AE}$" for cylinders.

![Figure 9. Rate changes caused by that damage coefficient and detection ($D_{AE}$)](image)

4. Conclusion

The obtained results prove significant sensibility of acoustic emission signal in this application domain. Based on the analysis of large data sets are selected suitable acoustic emission signal parameters, which can be used for more accurately diagnostics of condition of tested devices which could be used for development of pneumatic devices testing. Current results show good conformity and reproducibility. Acoustic emission application in this domain of diagnostics brings higher quality results than currently used methods. It is
evident that the diagnostics of pneumatic cylinder can be a new application domain for acoustic emission method. Intact cylinder and cylinder with a certain defect during operation, after evaluation of the signal (whether is from envelope signal or spectral analysis) are total unique characteristics. The conclusions of these measurements are summarized in the table and coefficient detection $D_{AE}$ determines the ability of the discovery of defects by acoustic emission. The coefficient detection $D_{AE}$ is lower than $D$ (greater probability of detecting defects), especially those defects that have a large coefficient of severity $S_2 (10)$ and a high coefficient of detection $D (7 -9)$ cylinders No. 4, 5, 12, 13, 14, 16 (NP07 defects, PP03, PP06, M03, M06).

The most serious defects of cylinders are those that have a large degree of severity $S_2$, which takes into account the worst possible consequences to the customer. As a criterion for a critical defect is determined by the product of the coefficients $S_2 \times D$ greater than 60.

**Acknowledgements**

This work is an output of research and scientific activities of the Technology Agency of the Czech Republic project No. TA04011374 "The new system is non-invasive diagnostics of pneumatic and hydraulic components" and was also supported by NETME Centre (New Technologies for Mechanical Engineering), Reg. No. CZ.1.05/2.1.00/01.0002 and, in the follow-up sustainability stage, supported through NETME CENTRE PLUS (LO1202) by financial means from the Ministry of Education, Youth and Sports under the „National Sustainability Programme I“ and by the project No. FSI-S-14-2329 “Vibro-isolation system of cosmic carrier payload” of the Faculty of Mechanical Engineering.

**References**


[2] KAWAMOTO, Sumire; WILLIAMS, Sam. Acoustic Emission and Acousto-Ultrasonic Techniques for Wood and Wood-Base Composites. Forest Products Research Institute, Ibaraki, Japan1 R. Chemist Forest Products Laboratory, Madison, Wisconsin


[8] Local Parker Cylinder Distributor. Industrial Cylinder Products Hydraulc and Pneumatic Cylinders. Catalog: 0106-7 (01/11), [cit. 6. 7. 2016]


