CONDITION MONITORING OF PNEUMATIC CYLINDERS BY ACOUSTIC EMISSION

Houssam Mahmoud¹, Pavel Mazal¹, Frantisek Vlasic², Miroslav Jana³

¹ Brno University of Technology, Brno, Czech Republic, mahmoud@fme.vutbr.cz, mazal@fme.vutbr.cz
² Centre of Technical Diagnostic ZD Rpety - DAKEL, Czech Republic, vlasic@dakel.cz
³ Policske strojirny a.s., Policka, Czech Republic, mjana@pos.cz

ABSTRACT

The present paper deals with the technical description of the acoustic emission detection technique in pneumatic cylinders with and without loading. The average energy of acoustic emission signal RMS gives a clear picture about scheme kinetic cylinder, and the different response between damaged and undamaged pneumatic cylinders with and without loading. Difficulties that faced the defect detection process are related to the types of the defects and the available methods for detection. The importance of detection process is due to the severity and the consequences that are caused by the defects after it occurs. A number of undamaged pneumatic cylinders were tested by acoustic emission, after that an artificial and described defects were made in the same cylinders. The results were compared to find distinctive differences that determine whether the cylinder is damaged or undamaged. The detection coefficient has been appointed for each cylinder by different types of non-destructive testing methods, whereas a set of cylinders, that are difficult to detect, were determined. So it is very difficult to find out the differences between undamaged and damaged cylinders in this set. The cylinders were loaded by different weights during their movement in horizontal and vertical direction and applied the same test.

Key words: acoustic emission, pneumatic cylinders, average energy, detection coefficient, loading, defects

1. Introduction

Cylinders are used in the majority of applications especially in movements that require limit speed. Pneumatic actuator convert fluid energy into straight line motion (linear actuators) [1]. It is necessary to detect the problems and their source as quickly and accurately as possible to continue operating. Each defect is undesirable, defects may affect the function of the product, cause disorder in the function. So the defects were simulated and made artificially: leakage, leaks in motion, galling and mechanical defects [2].
Acoustic emission (AE) is transient elastic stress waves generated by the energy released when microstructural changes occur in a material. The energy is provided by an elastic stress field in the material. The source of the AE signal may also be a variety of other processes - friction, flow, media leakage... These waves are detected by sensors (transducers) attached to the surface of tested elements; the sensors convert the mechanical disturbance to a voltage [3].

Detection Coefficient (DC) made the evaluation of defects easier. Values range of D, which was taken from the table FMEA (Failure Mode and Effects Analysis), is from 1 to 10 where 10 is very difficult to detect. The detection coefficients according to AE has small values, compared to the values of other previous methods [3].

Undamaged pneumatic cylinders were tested by AE, after that artificial defects were made at the same cylinders, the results were compared to find distinctive differences between the damaged or undamaged cylinders. In the previous study, undamaged and damaged cylinders were analysed using frequency spectrum within specified time [4].

A set of defects was identified and assigned through this comparison, but this parameter was not sufficient to identify all defects. Defects were sorted to sets according to the Detection Coefficient that takes high values. Frequency spectrum was replaced later by the parameter RMS during the monitoring of changes in the test results [5]. The results of the research proved the relation between RMS of AE signal and leakage rate and internal pressure when the internal pressure increases the leaking rate will be high and RMS of AE will rise [6].

For continuous AE signal, the most frequently used AE parameters are the Average Energy (AE_{RMS}) and the Average Signal Level (ASL) [7]. AE_{RMS} can be defined as:

\[
AE_{RMS} = \sqrt{\frac{1}{T} \int_{t_0}^{t_0+T} v^2(t)dt} = \sqrt{\frac{1}{N} \sum_{n=1}^{N} v^2(n)}
\]

where \(v\) is the voltage signal from an AE sensor, \(t\) the initial time, \(T\) the integration time of the signal, and \(N\) the number of discrete AE data within the interval \(T\).

General calculation of the maximum load on the cylinder is according to an equation for retreat stroke

\[
F = P \pi \left(d_1^2 - d_2^2\right)/4
\]

For progress stroke

\[
F = P \pi d_2^2/4
\]

\(P\) - pressure (kPa), \(d_1\) - cylinder diameter (mm), \(d_2\) - piston rod diameter (mm), \(F\) - force (N) [8].

2. Experiment

At Brno University of Technology, there are in the lab the experiment platform, test devices and some equipment including damaged and undamaged 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 and ZEDO. An executive scheme for the connection of components and experiment is shown in Fig. 1. The location of sensor is above of middle of the cylinder.
2.1 Parts of pneumatic cylinder
Understanding of defects requires a detailed knowledge of the parts of the cylinder. The cylinder contains a lot of parts. The main of them are given in Fig. 2.


2.2 Different types of artificial defects
Two types of defect were chosen, both of them have leak and high value of Detection Coefficient.
2.2.1 Unsealed O-ring thread piston and leakage - NP08, PP03

Defect was created at undamaged cylinder no. 8: unsealed O-ring between piston and piston rod to make leak between the piston and thread on the inner side. Checking with soapy water showed that the cylinder no. 8 has a leak around the piston rod. Measurement on ATEQ at the cylinder showed that the value of leak is 51 Pa/sec at a pressure below the piston (progress stroke), and the value of leak is 46 Pa/sec at a pressure above the piston (retreat stroke), (a suitable value for the actuator cylinder 6 Pa/sec) [10].

![Fig. 3: Leaks below the piston during progress stroke](image1)

![Fig. 4: Leaks above the piston during retreat stroke](image2)

When the piston extends to make the progress stroke, defects will be leak PP, so the load will be applied from above, as shown in figure 3. When the piston retracts to make the retreat stroke, defects will be leak NP, so the load will be applied from down, as shown in figure 4. The sensor has been fixed on the cylinder, and the cylinder was assembled under the table and the load was applied above the rod of piston, the signal was recorded from regress and retreat stroke.

3. Results and discussion

Loads will be applied on the cylinders during the test, to put the cylinder in other conditions, including some positions as horizontal and vertical, the aim is to enlarge the amount of leak. Two type of defect were presented in this study called NP, PP and the main parameter is RMS where one sensor placed on the middle of cylinder.

On the progress stroke, significant signal fluctuations are not exhibited throughout the movement of the piston from the initiation of the progress stroke until the piston cushion portion contacts the cushion seal. From that moment, there is an increase in the amplitude of the signal until it
stops (piston impacts the head cap cushion). A similar situation occurs during the retreat stroke, where the signal behaves similarly when the piston impacts the rear cap cushion. The sensor has been fixed on the cylinder, and the cylinder was assembled under the table and the load was applied above the rod of piston, the signal was recorded from progress and retreat stroke, and also the cylinder was assembled above the table and the load was applied below the rod of piston, the signal was recorded from progress and retreat stroke.

![Graphs showing RMS of AE signal during one cycle according to the load](image)

We recognize that RMS in retreat stroke in fig. b was very low after applying 21 kg also in retreat stroke in fig. d was very high comparing with the progress stroke.

![Graphs showing RMS of AE signal during one cycle according to the load](image)
c) Load 1 kg was applied above Cylinder

d) Load 21 kg was applied above Cylinder

Fig. 6: Relationship between RMS and displacement during one cycle according to the load

The total RMS was calculated for each loading and with different positions, progress and retreat stroke with above and below loading, as shown in the following table:

Table 1: The value of RMS according to load

<table>
<thead>
<tr>
<th>Loading kg</th>
<th>down progress RMS mV</th>
<th>Loading kg</th>
<th>down retreat RMS mV</th>
<th>Loading kg</th>
<th>up progress RMS mV</th>
<th>Loading kg</th>
<th>up retreat RMS mV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.04738</td>
<td>1</td>
<td>0.02780</td>
<td>1</td>
<td>0.04760</td>
<td>1</td>
<td>0.03317</td>
</tr>
<tr>
<td>6.5</td>
<td>0.05033</td>
<td>6.5</td>
<td>0.02580</td>
<td>6.5</td>
<td>0.03957</td>
<td>6.5</td>
<td>0.03967</td>
</tr>
<tr>
<td>11</td>
<td>0.05533</td>
<td>11</td>
<td>0.02239</td>
<td>11</td>
<td>0.03465</td>
<td>11</td>
<td>0.04103</td>
</tr>
<tr>
<td>16.5</td>
<td>0.06060</td>
<td>16.5</td>
<td>0.01864</td>
<td>16</td>
<td>0.03015</td>
<td>16.5</td>
<td>0.04603</td>
</tr>
<tr>
<td>21</td>
<td>0.06652</td>
<td>21</td>
<td>0.01661</td>
<td>21</td>
<td>0.02610</td>
<td>21</td>
<td>0.02762</td>
</tr>
</tbody>
</table>

From the table we can draw next four graphs:
We recognized that the relationship between RMS of AE and the loading is linear, this cylinder has defect so that clear that in the retreat stroke after applied 21 kg the cylinder is failure.

4. Conclusions

The last group of measurements, which are the subject of this article, discusses the two types of leakage that are difficult to detect.

An optimal amplification level must be defined, and therefore measuring the quality of a newly manufactured cylinder will need only one optimal AE sensor due to the high sensitivity of the AE.

The received signals are caused not only by defects, but also by mechanical movements, inlet and outlet pressurized air, temperature. The RMS parameter can evaluate the movements of pneumatic cylinders, particularly in combination with other monitored parameters.

The relationship between RMS of AE and the loading is linear. The loading on the cylinder make the defect clearer to discover and detect. The relation between the RMS and displacement explained all the position of cylinder during the work.

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6. References


