Expert estimation of leakage losses in the pneumatic systems in the bottling industry

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Abstract. By eliminating leaks in compressed air systems in manufacturing plants, up to 50% of energy can be saved. With a well-designed inspection and maintenance plan, eliminating the majority of leaks can be a routine and effective practice. This paper describes the results of a pneumatic leakage audits in manufacturing facilities from the bottling industry in Bulgaria. The results are analyzed and are defined major groups elements of the pneumatic system, which can be potential sources of leakage leading to significant losses of compressed air and determining energy efficiency in the production.

1. Introduction

Compressed air is a reliable source of energy and is widely used in industry and the service sectors thanks to its easy and safe production, transmission and use. In most industrial facilities, compressed air is required in a significant number of technological operations. The specifics of the production (industry), its scale and the structure of the production equipment, the life cycle stage, make the task of optimizing pneumatic systems multidimensional. With this regards, it is difficult to find a single, generally valid solution for improving energy efficiency when using compressed air [1].

On this basis, it is necessary to link the approach of researching and summarizing the most effective measures to optimize the pneumatic systems to the relevant production or industry. For example, specific industries are subject to analysis in the papers [2,3,4], etc., respectively the woodworking, pharmaceutical and mining industries.

Compress air (CA) leaks are one of the largest sources of energy loss in pneumatic systems and eliminating them in order to improve the energy efficiency of compressed air is of primary importance. In terms of effort and resources, this is also the most effective, conventional measure.

On top of energy loss, CA leaks inflict pressure drops in the system. This effect to the operation of air-powered equipment and tools, and lead to reduction of production efficiency. Leaks cause significant losses, often up to 50% of the CA produced [5,6].

Despite of the recent development and availability of modern equipment, identifying leak points and calculating the flow rate of compressed air losses, caused by them, is a labour-intensive and time-consuming task [7,8].

In the bottling industry like a soft drink, mineral water, beer, etc. production, the main functional modules of bottling lines are similar, regardless of the product manufactured. Most often, they include (Fig. 1) de-palletizer, filling machine, inspection and marking section, automatic labelling machine, automatic multiple shrink wrapper and palletizer. In some industries, depending on the type of individual packaging, a PET blow-molding machine is included in the production line. The main part of the manufactured CA in a bottling plant used in these modules is for linear and rotary actuating, vacuum operations, blowing and drying, transportation, etc. [9]. In these modules are observed greatest losses of CA. Therefore, a systematic approach and prioritized leakage detection and
repair is essential to the maintenance.

![Figure 1. Main functional modules of bottling lines](image)

2. Detection and sizing of leaks - measuring equipment, software

2.1. **Soup Liquid Method**

In this method, the suspected leakage area is covered with soapy liquid, which, in the presence of leakage, begins to form air bubbles. The size of the bubbles can be used as a basis for determining the size of the leak. This method is cheap and easy to use, but it may be more time-consuming compared to other methods.

2.2. **IR Thermography Method**

The infrared technology uses IR thermovision cameras to measure thermal energy emitted by an object. These cameras allow very accurate contactless temperature measurement. In almost all compressed air systems, a malfunction or leakage of air lead to change in the temperature. Thermal or infrared energy is a light emission that is invisible to the human eye due to the high wavelength. This is the part of electromagnetic radiation that is popularly known as heat or thermal radiation. Unlike visible light, in the infrared spectrum, any object with a temperature above absolute zero emit heat. Thermography is successfully applied in the audits of pneumatic systems. An infrared camera can record temperature changes in the installation and detect damage or leakage locations [10].

2.3. **Ultrasonic Method**

Ultrasounds are generated by the turbulence of a flow inherent in the leakage of a CA. In the event of a leakage from a CA system, the friction of the air at the edges of the orifice from which it flows is an ultrasonic source. The effect does not depend on the size of the leak, its flow rate or the size of the opening. Consequently, ultrasonic leak detection is the industry standard and one of the most effective methods for detecting it.

Ultrasonic detectors are relatively easy to use and can detect leaks that cannot be heard with the naked human ear. In addition, during the inspection with such equipment, it is not necessary to interrupt the production cycle, as the background noise does not affect the results. Ultrasonic leak detection is classified as active, passive and vibroacoustic. This study used passive ultrasound detection to quantify compressed air leakage.
3. Inspection and analysis of losses of compressed air caused by leakage in bottling industries

The analysis is based on the results of audits of CB leaks at 10 factories in the bottling industry in Bulgaria - bottling of mineral water, soft drinks and production and bottling of beer. The timeframe of the survey is the period 2017-2019.

The leakage audit involves a thorough inspection using an ultrasonic detector.

The elements of the pneumatic systems under examination are classified into 9 groups as follows:

1. Actuators - including all types of pneumatic actuators: cylinders – with rod and rodless, rotary actuators, pneumatic grippers, pneumatic actuators of process valves, etc.
2. FRL (Filter-Regulator-Lubricator) - Including all elements of FRL or individual elements - filters, regulators, lubricators and their manually or automatically shut off valves, pressure gauges, pressure switches and flowmeters (if are part of module of the FRL).
3. Single Valves - this group includes standalone valves, whether used for actuator control or for other purposes (excluding those in the pneumatic preparation group FRLs).
4. Valve islands - includes valves and distributors of block assembly, common base, with or without common power supply and wiring, with or without communication modules and all elements adjacent to the block.
5. Fittings - Includes all Push-in quick connectors regardless where they are mounted.
6. Speed regulators.
7. Tubes and connectors. This group covers leaks in flexible tubes and hoses, as well as the connections between them - fasteners, fittings, clamps, nipples, couplings, etc. without Push-in fittings.
8. Bottle grippers and gripper heads (Fig. 2) - Specific items for bottling industry, mainly used in palletizers and de-palletizer for manipulating bottles. They are separated into a special category because of their specificity and the significant losses of compressed air that generate the leaks detected in them.
9. The last group covers all other leaks detected in the pneumatic system: highways, vacuum elements, etc., which are not included in the first 8 groups.

4. Instrumentation

The intensity of the ultrasonic waves generated by the leakage during the examination of the bottling companies was measured with an ultrasonic detector SDT200 [11]. The technical specification is presented in Table.1.
Two sensors from the SDT200 package were used - the sensor integrated into the unit and a flexible sensor with a flexible body length of 550mm and a focusing tip and a spacer from the sensor - 25mm. The leakage measurement distances are 40cm, 20cm or 2.5cm.

The SDT200 measures the ultrasonic signal, converts it to audio through heterodyne, and amplifies it for audible signalling to headphones. The dimension of the detected signal is dBμV.

The conversion of the dBμV signal values recorded by the SDT200 to volumetric flow rate (l/min, m3/h) is analytic using the Field Leak Estimator v.2014, (Fig. 3 and Fig. 4). The reading is calibrated for a flexible 40cm (1.3ft) sensor at 6bar, 20 and 2.5cm (correction with -6 dBμV for each double shortening distance). Which means, for measurements of 20 cm the correction is -6 dBμV, for measurements of 2.5 cm the correction is -24 dBμV.

It should be noted that the conversion is considered approximate. In practice, many factors can influence the result, such as the size and shape of the opening, the profile of the walls, etc. [11].

**5. Results and Discussion**

During the survey, 1328 significant (over 5 l/min) leakages were detected in the CA systems of the factories examined. The summary results are given in Table 2.
Table 2. Summary results

| Summary results       | Number | %     | Leakage l/min | % of total loss | Average leakage (l/min) |
|-----------------------|--------|-------|---------------|-----------------|-------------------------|
| Fittings              | 457    | 34.41%| 13042,90      | 29.77%          | 28.54                   |
| FRL                   | 240    | 18.07%| 7547,83       | 17.23%          | 31.45                   |
| Bottle grippers       | 125    | 9.41% | 6174,05       | 14.09%          | 49.39                   |
| Tubes and connectors  | 106    | 7.98% | 3931,27       | 8.97%           | 37.09                   |
| Single Valves         | 99     | 7.45% | 3231,08       | 7.38%           | 32.64                   |
| Others                | 94     | 7.08% | 3206,20       | 7.32%           | 34.11                   |
| Actuators             | 81     | 6.10% | 3090,93       | 7.06%           | 38.16                   |
| Speed regulators      | 75     | 5.65% | 2134,56       | 4.87%           | 28.46                   |
| Valve islands         | 51     | 3.84% | 1449,61       | 3.31%           | 28.42                   |
| **Total**             | 1328   | **100.00%** | **43808,42** | **100.00%**    | **32.99**               |

The distribution of leakages by group of elements is shown graphically in Fig. 5 and 6 shows the ratio of leakages between the groups, respectively, in number and total losses in l/min.

The following conclusions can be drawn from the results of the survey in bottling companies:

1. Leaks in 4 of the predefined groups - Fittings, FRL, Bottle grippers and Tubes and connectors - represent more than 70% of total losses. The large number of leaks in the Fittings group is not surprising because their number in the pneumatic systems is the largest, and their diversity in quality and prices on the market is also significant.

2. Bottle grippers are a specific element of the pneumatic system in bottling lines and can generate very large losses from compressed air leaks.

3. The commonality between the four groups of items, generating 70% of losses (Pareto chart, Fig.7), is that, unlike actuators, speed regulators, valves, and valve islands, they are easily accessible and quickly replaceable with relatively little down time.
The average leak by group, with the exception of Bottle grippers (Table 2), show that targeting a specific group of components will be not more effective (in terms of air losses) than complex removal. We can see this on Fig.5, where differences are largely determined by the presence of a small percentage of strongly divergent points. On other hand, removing a large number of small leakages can be irrational. However, it can be concluded that about 70% of leaks can be removed by leakage repairmen in the first four groups of components of pneumatic systems.

In this study, we used a passive ultrasonic method for detecting leaks in the compressed air system, which is indirect, non-contact and although accepted as best practice in leak detection, problems with single leak sizing are not neglected. However, many researchers and analysts, including manufacturers of such detectors stands that when detecting and measuring a large number of leaks, the overall results are sufficiently reliable and give a good practical idea of the energy losses generated by leaks in the compressed air system.

The resulting statistics can be used to plan and prioritize the service activities of components in the pneumatic systems.

6. Conclusion

This paper summarizes and analyses the results of 10 compressed air leakage audits at bottling companies. Four main groups of elements of the pneumatic system were defined, contributing to over 70% of losses. The statistics obtained give a realistic idea of the scale of losses caused by leaks. A problem that cannot be permanently resolved over time. The results may find application in training of the maintenance staff, developing a plan for the maintenance of the pneumatic systems, or in the overall task of improving the energy efficiency of production lines.

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