FACTA UNIVERSITATIS
Series: **Mechanical Engineering** Vol. 7, N° 1, 2009, pp. 37 - 60

IDENTIFICATION OF THE POSSIBILITIES FOR INCREASING ENERGY EFFICIENCY IN THE COMPRESSED AIR SYSTEMS

UDC 621.5.011

Dragan Šešlija[1], Miodrag Stojiljković[2], Zoran Golubović[3], Vladislav Blagojević[2], Slobodan Dudić[1]

[1]Faculty of Technical Sciences, Univesity of Novi Sad,
Trg Dositeja Obradovića 6, 21000 Novi Sad, Republic of Serbia,
[2]Faculty of Mechanical Engineering Niš, Univesity of Niš,
Aleksandra Medvedeva 14, 18000 Niš, Republic of Serbia,
[3]Faculty of Mechanical Engineering Belgrade, Univesity of Belgrade,
Kraljice Marije 16, 11000 Belgrade, Republic of Serbia,
E-mail: seslija@uns.ac.rs

Abstract. *This paper presents the basics of the managerial approach to increasing energy efficiency of the compressed air systems, and the identification of the possibilities for efficient production, preparation, distribution and rational consumption of compressed air as well as the ways in which they can be applied for increasing the energy efficiency.*

Key Words: *Energy Efficiency of Compressed Air, Filtration of Compressed Air, RFID*

1. INTRODUCTION

The effort to increase energy efficiency is a general trend worldwide. A significant segment of this area is the increase in industrial energy efficiency, whose significant portion belongs to pneumatic and electro pneumatic automation systems.

The compressed air systems are reliable, safe and very well suited for performing numerous functions, but their economic efficiency is, however, rarely taken into account. They represent a significant energy carrier in industrial environments, business systems and public sectors and that is why the compressed air installations are considered to occupy the fourth position in the order of significance, just after electrical energy, gas and water. However, unlike the first three, the compressed air is the only resource produced on the site of its use, which renders its users the complete supervision over the entire process. Unfortunately, direct measurement of the consumed air is not an established practice; this can also be said about calculations of the thus created costs.

Received June 26, 2008

Good quality and reliability of operation of these systems are accomplished with good system management, which is described in detail in [1], [2], [3], [4]. This enables significant savings of the consumed energy, prolonged component's life cycle, more reliable system operation and lowered system operation costs. There are significant issues that influence the overall increase in energy efficiency of the compressed air systems, which are explained in greater detail in [5], [6], [7], [8], [9].

1.1 Reasons for Increasing Energy Efficiency of the Compressed Air Systems

It is often wrongly assumed that the costs of the compressed air are so low that they do not justify the expenditure of the expensive managerial time for optimizing all the parameters included in this problem. However, the air is free of charge only before compression and injection into a compressed air system. After compression, its price can have an impact on the redistribution of some compressed air consuming application to alternate energy sources.

The problems in the compressed air systems are rarely caused by insufficient compressor capacity or insufficient pressure that they produce. The most frequent causes of problems are unrealistically defined consumer demands, operation of the control system, inadequate compressed air reservoir, inappropriately designed distribution system, inadequate separation and filtration of the most significant pollutants: water, compressor oil, dirt, rust and other particles of any kind.

Three essential reasons constitute the grounds for the movement that requires investments of finances, time and effort into increasing energy efficiency of pneumatic systems:

- Savings in energy and money through identification and elimination of loses, which will consequently, reduce the system operation costs,
- Improvement of reliability and performance of the entire compressed air systems, which will prolong the component's life-cycle,
- Reduction in energy consumption in order to subsequently lower the emissions of dangerous and polluting substances, which will lessen the influence on the environment.

An adequately designed, properly realized and well-maintained compressed air system can save thousands of euros every year. Besides, increasing the reliability will decrease the risks of production disruption while ecological effects will be improved as well as the influence on human health.

The potentials are great for reducing energy consumption in compressed air systems, and they can be realized with small to medium investments. Table 1 gives examples of potential energy savings for a compressed air system operated at 7 *bar* with a capacity of 0,5 m^3/s. We have considered small investments to be in amounts smaller than 3.000 EUR while medium investments range from 3.000 to 15.000 EUR. The displayed percentages of potential savings are only indicative; they vary from one system to another and are not cumulative, but serve as a good reference point for orders of magnitude of potential savings.

Development and application of an adequate system policy (setting of goals and ways of their realization) is the most efficient way of increasing energy efficiency in pneumatic systems. The main elements of this policy are described in Chapter 2. Any of the managerial actions presented can be included in an already defined policy for compressed air systems (also, all of them can be applied simultaneously).

Table 1 Possibilities for energy savings in a typical industrial compressed air system [6]

	Potential savings	Investment
Managerial actions		
Strengthening the awareness of all users regarding the adequate use of compressed air systems	10 – 15%	Small
Development and application of a maintenance program for the overall system	5 – 8%	Small
Installation of measuring equipment and applying measurements and acquisition program	5 – 10%	Medium
Working exclusively with personnel that is well trained for installation, servicing and upgrading of a system	5 – 10%	Small
Development and application of the policy for equipment purchasing	3 – 5%	Small
Technical actions		
Application of the program for identification and removal of leaks	20 – 40%	Small
Do not keep the installation under working pressure when production line is not operating	2 – 10%	Small
Implementation of control adjusted to real dew point if the existing dryers do not posses it (for adsorption and refrigerating types of dryers)	5 – 20%	Medium
Improvement of compressor control	5 – 15%	Medium
Application of heat regeneration measures wherever they are applicable and economically justifiable	up to 75%	Medium

The most significant side effect of increasing energy efficiency is the ecological one. Efficient use of pneumatic systems in industry does not only increase company profit but also significantly contributes to climate effects. Up to 2% of total CO_2 emissions produced by industry may be avoided by an efficient usage of pneumatic systems. Also, appropriate filtering and condensate treatment can prevent the release of contaminants into the environment.

The climate change protocol signed in Kyoto 1997, among other things, determines the reduction of emission of harmful substances into the atmosphere, individually for each state and also a more efficient usage of energy sources. This particularly relates to substances that can create a greenhouse effect. This protocol establishes the reduction of CO_2 emissions, as the main pollutant, for 6% during year 2010. According to this protocol, the European Union must reduce the emission of harmful substances by at least 8% with respect to the level from 1990, in the period starting from year 2008 to 2012. Since the pneumatic sector is also obliged to do the same, as an industry sector, it means that this area also needs to reduce its energy consumption, as much as possible. The European Union has presented a thorough overview of energy consumption for pneumatic systems, which also contains details regarding potentials for savings in energy [10].

Energy efficient pneumatic system can be defined as the one being:

- appropriately designed to reduce pressure drop taking into account all elements of fittings, valves, preparation groups and pipelines,
- regularly supervised with tracking of values for specific energy consumption based on the data collected,
- well-maintained with all needed service work, necessary replacements for equipment in predetermined terms and tests,
- used by the staff aware of significance and expenses generated in a compressed air system, which is also trained to use the given equipment in an adequate, energy efficient sense,
- permanently subjected to a program for identification and removal of compressed air leakage points.

Thereby, every component installed in a compressed air system should provide an adequate contribution in order for an end user to receive the required quantity and quality of compressed air. In addition, the air delivered to each individual consumer must have appropriate pressure whose value is free from fluctuations. Systemic approach is very important because all the components of a system constitute a chain which supplies the end user with energy contained in compressed air, and they are all interacting among each other and that is why they should not be considered separately.

For example, it often happens that the factory management perceives a problem in a compressed air system; but instead of exploring its cause in its entirety, it opts for a partial solution such as the acquisition of a new compressor. The case may very well be that the leakage rate is so high that its mere reduction would show that the acquisition of new compressor is obsolete. Or, it may be possible that the diameter of compressed air distribution network is too small, so the pressure drop rises to, for example, 3.9 *bar* instead of recommended value of 0.1 *bar* (the authors experienced this in practice). In that case, again, the acquisition of a new compressor does not solve the problem.

1.2 Investing in Energy Efficiency Improvements

The problem of investing in energy efficiency improvements of pneumatic systems should be approached with great caution. It is often the case that the purchasing of more energy efficient equipment introduces higher expenses than a less efficient alternative, which can mislead the personal responsible for purchasing to overlook the total operational costs of those systems and opt out in favor of a less energy efficient alternative. Thus, the policy of the lowest purchasing price can exert a detrimental influence onto increase in energy efficiency and also any other kind of technological advancement.

As a general rule, an approach to equipment acquisition process should be adopted which, instead of comparing the investment prices, encompasses the overall working life expenses, whose only minor part belongs to investment price, as illustrated for a typical example in Fig. 1.

The example in Fig. 1 relates to the exploitation period of ten years, where it can be seen that energy costs are four times larger than the compressor's purchase price. It can be seen that maintenance costs participate in a significant share and have essential influence onto a proper and energetically efficient operation of the whole system.

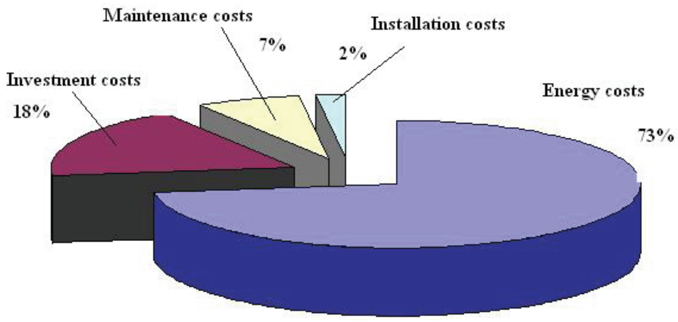

Fig. 1 Cost structure for a life cycle of a typical compressed air production system

2. Overview of Worldwide Experiences in Increasing Energy Efficiency

Results of numerous studies have shown that in many factories using compressed air efficient expenditure attributes to one half, or even less, of total compressed air production. Based on the data of U.S. Energy Department, compressed air systems participate with up to 1% in total annual electrical energy consumption, which is equivalent to one and a half billion dollars. In Germany, air compressors consume approximately 14.000.000.000 *kWh* every year.

Many studies, conducted worldwide, have investigated the field of energy efficiency in pneumatic systems and also the potentials for applying the measures for energy savings, and two of them excel in their importance.

A study conducted for the needs of U.S. Energy Department [11], presents the state of energy efficiency of pneumatic systems in U.S. industry. One of the conclusions of this study was that applying the measures for increasing energy efficiency, whose turnover period is 3 years, can yield savings that, on the level of entire industry, average around 17.1%. If all these measures were to be applied, the energy savings for entire U.S. would amount to 15.760 GWh annually, or around $747 millions. Other important conclusions were:

- The awareness of users regarding energy efficiency is on a very low level because only 9% examinees have identified energy cost management as a primary goal in administrating and maintaining pneumatic systems, while only 17% have mentioned energy efficiency as one of their goals.
- Maintaining a consistent and reliable supply of compressed air was the main goal of system management, as recognized by as many as 71% of participants in this study.
- A significant number of examinees reported having serious problems in operating and maintaining these systems. Thirty five percents of examinees experienced loses due to unplanned disruption of production, caused by inadequate compressed air supply, and for 21% of them this disruption lasted for 2 or more days. Most often reported operational problems were excess moisture and inadequate pressure.
- The programs for reducing air leakage in compressed air systems were conducted by 35% of the companies participating in this study.
- The level of implementation of measures for increasing energy efficiency is very low since more than 57% of all factories took no measures, during the previous two years, to increase energy efficiency of pneumatic systems, or to remove leakages.

- The majority of interviewed equipment manufacturers consider the increase in energy efficiency services as crucially important for their competitiveness in today's market.
- The majority of interviewed equipment manufacturers have identified the lack of user's awareness regarding advantages of the energy efficiency increase as a main barrier to a wider distribution of these kinds of services.

A study conducted for the needs of the European Union [10] presents an overview of the state in this field on the level of the EU membership countries, as well as an estimate of the states in countries that were associated after the completion of this study. The study focused on users having systems within a power range of 10 kW to 300 kW. The units that are below this range, although largest in the number, participate with a small share in the total compressed air consumption. Larger compressors, with power over 300 kW, are most often devices that are customized and embedded into well-designed and maintained systems, which are not subjected to energy efficiency measures hereby addressed.

The total amount of electrical energy used by compressed air systems in the EU countries averages to 10% of total electrical energy used by industry [10], and ranges from 7% in Germany and 10% in Great Britain, all the way to 11% in France, Italy and the rest of EU.

Also, in this study, an estimate is given for the compressor's life cycle which serves as indicative data when compared to those of the Serbian industry:

- 13 years for compressors ranging from 10 to 110 kW,
- 16 years for compressors ranging from 110 to 300 kW

Estimated average loses generated before the compressor outlet (power drive loses, cooling loses, etc.) are 15%, while an average annual operation period is 3500 hours. Furthermore, this study proposes an array of measures, necessary actions and legislative regulations on the level of EU that are needed to improve the current state.

3. Management of Compressed Air Systems

Introducing measures for increasing energy efficiency is not solely related to the compressed air production (compressors, preparation and distribution) but it is equally important for the compressed air consumption.

3.1 Overview and Analysis – System Audit

Prior to initiating any improvements in a compressed air system, it is necessary to conduct a detailed inspection – system audit in order to:

- determine total annual costs, and,
- establish the initial state, as the basis for comparison with future improvements already accomplished.

If the continuous acquisition of system performance is already implemented then it is possible to derive a consumption profile and, by analyzing the behavior of performance parameters, identify the areas of possible reduction or complete elimination of losses.

Usually, the implementation of this kind of measurements requires energy consumption sensors, flow sensors, pressure sensors, recordings of on/off time's compressors and, if required, for other pieces of equipment (dryers, condensate separators, etc.).

If measurements are not performed it is possible to evaluate energy consumption for each compressor based on the size of the power drive, average degree of exploitation and number of operating hours.

After the system audit, it is necessary to reach decisions, within appropriate management structure, that introduce norms for compressed air systems.

3.2 Establishing Norms for the Compressed Air System

The majority of compressed air systems are created by evolvement from the initially designed state. The coming of the new compressed air machines also meant increasing demands so that the upgrading of the existing system gradually took place. Such systems are unlikely to be optimal since they have not been subjected to structured designing process.

During the design process, consultations with production department, maintenance, accounting, energy and environment protection departments should take place because the jurisdiction over the compressed air system throughout the phases of design, purchasing, implementation and exploitation is a matter of interaction among the given departments. Such structure, without assigning the responsibility for functioning of the compressed air system to one person, often introduces an uncoordinated approach to changes within the system eventually leading to conflicts in needs of different departments.

In order to prevent such occurrences, it is necessary to establish the principles of compressed air system operation that are jointly agreed upon, and to constitute the norms of quality for compressed air, required pressure level and required flow. Thereby, the grounds are set for an efficient system operation and an energy consumption reduction. Moreover, this approach increases system reliability while satisfying all legislative obligations.

- assign the responsibility to one manager in order to secure overall coordination of compressed air system management,
- set the goals, taking into consideration:
  - the role and responsibility of each department,
  - raising the awareness of everybody involved in usage of compressed air,
  - establishment of the price of compressed air,
  - setting the achievable goals for loses reduction,
  - implementation of the maintenance program
  - defining the procedures for servicing and installation that will be executed by well-trained personnel,
  - defining the equipment acquisition policy.

Thereby the defined approach to management of the compressed air system has within itself the same principles that are contained in general energy management so it has a significant role for achieving maximum in energy consumption of the entire system. Reduction of energy consumption in the compressed air systems to 30% is a frequent and achievable goal.

3.3 Identification of Possibilities for Improvement

The identification of possibilities for improvement ought to be a significant managerial activity, although the mere realization of these possibilities belongs to matters of technical actions. Namely, a good manager must have an overview of the system entirety and urge the technical department to identify all the possibilities for system improvement so that he can, based on his own perception of needs of the whole production or sometimes the entire business system, decide which option, of the identified ones, is to be implemented and when.

It is advisable to begin with the analysis of end users because every improvement reflects mostly on total compressed air demand as well as on the adequate distribution network (for example, example unnecessary works on the pipeline and reduced pressure loses). Based on a well-done system audit a certain number of actions can be identified while the others will result from a more elaborate technical analysis of the system.

In Chapter 4 we have outlined in detail the identified possibilities for improvement of energy efficiency in the compressed air systems.

3.4 Maintenance

Effective maintenance is of crucial importance for energy efficiency of the compressed air system. If a company withholds the resources (people, money, spare parts, equipment) needed for regular maintenance, this will backfire in significantly higher energy consumption, reduced life cycle and reliability of components and of the entire system.

The manager must insist that the plans that are created should take into consideration, aside from necessary technical parameters, the need to increase energy efficiency. Particularly large effects are achieved if the replacement period for filter components is determined experimentally.

By law, compressed air reservoirs belong to category of pressurized vessels, which makes them a subject of mandatory inspectional examinations, which secure the reduction of potential risks to human health and safety. Such examinations should be used for checking all the record keeping related to maintenance of these systems and, if needed, for recreating maintenance periods because maintenance periods are not identical to every piece of equipment. Moreover, even the periods for same pieces of equipment need to be reduced if the equipment has aged and/or is more excessively used.

3.5 Awareness of the Employees and Their Involvement

Many users of compressed air do not realize how expensive a medium compressed air is, and they are prone to its immoderate and unjustified use. The companies which have invested the effort in training their personnel to understand and appreciate:

- the costs of production, preparation and distribution of compressed air,
- the interdependence of components within a compressed air system,
- the significance of energy savings,

have managed to create the largest savings in this field.

4. The Possibilities for Increasing Energy Efficiency in the Compressed Air System

The establishment of measures for rational consumption, efficient production, preparation and distribution of compressed air is important for improvement of energy efficiency. It is possible to significantly improve the energy efficiency in this segment of technical systems with the procedures for optimizing a pneumatic system, for rationalizing its application, by establishing the necessary and sufficient quality of compressed air and appropriate equipment selection, by good management, and by applying adequate control software and proper maintenance of the compressed air system.

Due to its inappropriate use, aside from all advantages, compressed air can become the most expensive form of energy for performing work in industrial plants. The costs of compressed air are often unknown or hidden within other operation costs. In the majority of plants only a portion of total compressed air production is used in an efficient manner. The problems with pressure levels are rarely caused by the compressor's capacity or the low pressure that they can produce. The most frequent causes of problems are the operation of a control system, unrealistically defined consumption demand, inappropriately designed and maintained distribution system and unbalanced reservoir capacity.

Fig. 2 shows the chain that connects the source of electrical energy to the end consumer.

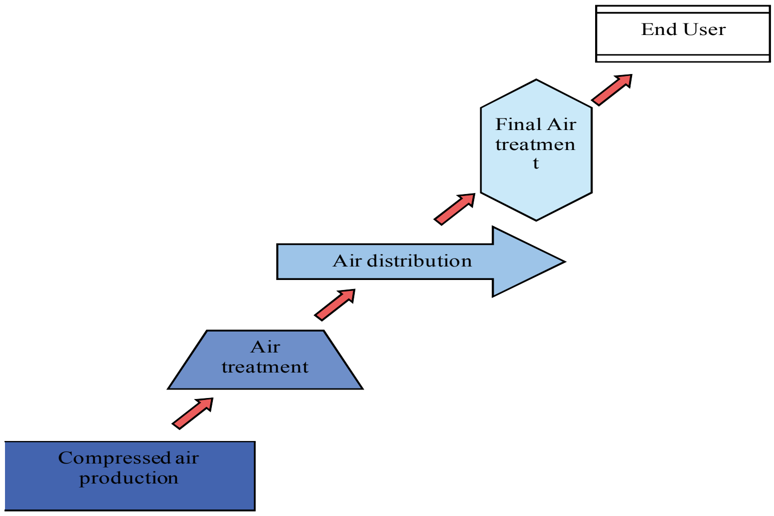

Fig. 2 The process chain for a compressed air system

The system operation depends on the properties of each element but even more on the design of the entire system.

The following technical measures have been identified that can improve the functioning of the entire process chain of a compressed air system:

- power drive improvement; usage of high efficiency drives; integration of variable speed drives,
- optimal choice of compressor type, as a function of specific needs of end users,
- improvement in compressor technology, particularly in the segment of multistage compressors,
- application of sophisticated control systems,
- regeneration of the dissipated heat and using it in other functions,
- improvement of compressed air preparation: reduction of pressure and energy lost in processes of cooling, drying and filtering; optimization of filtering and drying as a function of consumer needs and temperature conditions,
- overall system design, including the systems with multiple pressure levels,
- reduction of pressure losses due to friction in the pipeline,
- air leakage reduction,

- reduction of operation pressure,
- optimization of certain devices that consume compressed air: application of more efficient, better adjusted devices or, in some cases, replacement of compressed air with an electrical drive,
- recycling of used compressed air,
- measuring and recording the system performance.

Judging by the findings of numerous studies, the measures stated can increase energy efficiency of the pneumatic systems and all of them can be reimbursed (with the most frequent period for investment reimbursement of less than 3 years).

4.1 Power Drive Improvement

Usage of high-efficiency power drives increase's energy efficiency. Integration of variable speed drives (VSD) into compressors can lead to energy efficiency improvements with respect to characteristics of the load.

Application of high-efficiency drives renders the largest savings to new systems, because the chances of users installing high-efficiency drives into existing compressor systems, without changing the compressor itself, are rather small.

Integration of speed controllers (frequency inverters) into compressed air systems is a very cost-effective measure, under the conditions of variable demands, and it is estimated that such systems participate in the industry with 25%.

In cases of multi-compressor stations, variable speed drives are integrated into only one machine and are usually coupled with more sophisticated control system for the whole compressor station that powers on and off individual compressors with a constant speed and also varies the speed of one compressor in order to adjust the production of compressed air to instantaneous requirements of consumers.

4.2 The Optimal Selection of Compressor Type

The segment of the market covering power range from 10 to 300 kW is now dominated by rotary screw compressors with oil injection – it is estimated that around 75% of compressors sold in EU belong to this category [10]. Besides, there are other compressor types available that have other advantages within certain exploitation characteristics.

In order to make an optimal selection of compressor it is necessary to consider the specifics of the user's compressed air system. The choice of compressor can greatly influence the energy efficiency of the system, with respect to compressor performance but also regarding multiple interactions with other elements in the system. The advantages of multi-compressor systems are especially emphasized in production systems with the high workload that operates almost continuously.

4.3 Improvements in Compressor Technology

A whole array of efforts is directed towards improving the existing compressor lines but also towards the development of new types, which are usually customized to different segments of industry. Another aspect of research is concerned with improving production methods such as applying narrower tolerances in order to reduce the leakage within the compressor.

It must be taken into consideration that the laws of thermodynamics limit further improvements of the compressor so that only minor improvements can be made in the area of energy efficiency, while the greatest potentials lie in an adequate design of the entire system and of the procedures for system control and maintenance.

4.4 Application of Sophisticated Control Systems

Sophisticated control systems are applied in order to adjust the compressor outlet flow to the consumers' requirements. They save the energy by optimizing the transition between non-loaded working state, loaded working state, and non-operating state of compressor. Sequencers optimize the operation of multi-compressor stations and can be combined with applications of variable speed drives. Predictive control uses fuzzy logic and other algorithms to predict the future behavior of consumers, considering the history of system behavior.

Since the price of electronically-based control technologies is decreasing and industrial familiarity with its usage is simultaneously increasing, their usage is rapidly expanding and their applications to the compressors are more frequently taking place. This kind of control can be purchased along with new machines but can also be applied to existing systems.

4.5 Regeneration of Dissipated Heat

Compressors intrinsically generate heat, which can be, under certain conditions, used for other functions. The recommendations for its usage depend on the presence of those consumers of thermal energy whose characteristics comply with the amounts of generated heat, whose usage is enabled by adequate equipment (heat exchangers, pipelines, regulators etc.) the price of which is favorable in comparison with alternative solutions. The design of the heat regeneration system must provide for appropriate compressor cooling. The heat dissipated by the compressor is in most cases too low in temperature, or too limited by its quality to adequately respond to the needs of industry regarding their main processes or heating. The climate and seasonal changes also influence the ratio between investments and yields. Typical application is heating the space close to the location of compressor, when needed. Possibilities for using the compressor recycled energy are:

- Used in buildings (Water heating and Building Heating),
- Compressed air preparation (Standard dryer regeneration, Integral dryers with compressor),
- In processes (Heating, Drying),
- Boiler preheating (Drinking water, Boilers).

The cost efficiency of heat regeneration depends on available alternative energy sources. It could be very cost-effective, only if it is alternative to electrical energy. However, if natural gas is available, or the process residual heat or gas, the cost efficiency of regenerated heat is much smaller.

4.6 Improvements in Preparation of Compressed Air

A well-prepared compressed air has the following two significances:

- *Prevents damaging of the production equipment.* The impurities contained in the compressed air can cause malfunction of production equipment that uses it. The appropriate quality of the compressed air increases the reliability of equipment using it.
- *Increases product quality*. In some production systems, compressed air enters the end product directly or comes into contact with the end product (for example in food production, pharmacy or electronics). In these cases, poor compressed air quality leads to decrease in the end product quality.

The equipment for drying and filtering causes the pressure to drop while dryers often consume electrical energy or partially use compressed air for their operation and regeneration. Because of that, the optimization of compressed air preparation as a function of the user needs is one of the main sources of energy savings.

The possible measures are:

- the dynamical setting of the degree of drying in accordance with external temperature conditions. This is applicable only when the purpose of drying is to keep the air temperature above the dew point in order to prevent the condensation from occurring within the system. This measure can be inappropriate if drying is required to fulfill the precisely defined needs of a process with respect to compressed air quality.
- to optimize the degree of particle filtering as well as oil and oil vapor filtering, so that it can precisely match the needs of the system. Excessive filtering leads to an unnecessary waste of energy. The importance of this problem is worked out in detail in Chapter 4.6.1.
- increase the filter capacity. The increase of the number of filters in parallel operation decreases the speed of air and thus reduces pressure loss. This investment can be very cost effective for new as well as for existing systems.

4.6.1 Optimization of filtering process

In order to optimize the filtering process it is necessary to [5], [12], [13], [14], [15]:

- identify the possible filter locations,
- define the flows, pressures, temperatures, allowed pressure drops, compatibility and needs for validation in critical places,
- define the types and concentrations of contaminants (particles, water, oil, oil vapors, biological load, etc.) in characteristic locations,
- determine the needed retention efficiency and number of filtration stages for each characteristic location,
- choose the adequate filter elements for each location, and,
- choose the housings for each characteristic location.

Every aspect of the previous algorithm deserves special attention. When the selection of filter elements is in question, they are generally expected to have a high throughput, large filtration surface, high mechanical resilience, high thermal resistivity, high contamination capacity, long operation period between the services, low price and low exploitation costs as well as appropriate certification, the possibility to fulfill quotas, standards and legislature requirements in their area of application.

Proper dimensioning of filters is a precondition for energy efficient functioning of pneumatic systems [15]. Under dimensioning a system will disable it from fulfilling its task or, in the best case, enable it for short term fulfillment – quickly a clog will occur. Overdimensioned system is often only partially used, and it is rarely the case that its entire capacity is uniformly exploited, while requiring higher investment costs. Each filtration system should be dimensioned with a safety margin, which must be determined based on well-determined initial exploitation conditions and final conditions of filtration.

It is possible to present general guidelines for the selection of the right filter. However, it is advisable to comply with the filter manufacturer's requirements. If the filter manufacturer gave no recommendations, it is possible to follow the general guidelines listed in Table 2.

The maintenance of all components of the pneumatic system is a precondition for its energy efficient functioning. The malfunctioning of one component in a pneumatic system can generate new pollutants that emerge from component wear and tear (valves, distributor pistons, sealing, etc.). In such system filters are subjected to additional load, which is not accounted for in filtration design. This can cause its accelerated wear or clogging.

Table 2 General guidelines for the selection of the filter type

Filter type	Application	Max. ΔP with working pressure of 7 [bar]	Special demands
Regular filters	Particle removal	0,14 - 0,5	No
Coalescent	Removal of all particles and fluids	0,17 - 0,7	Installation of an ordinary pre-filter
Absorption	Removal of fumes and odors	0,0017 - 0,13	Installation of ordinary and coalescent pre-filters
Microbiological	Removal of biological load	3,0 - 5,3	Installation of ordinary, coalescent and absorption pre-filters

If filtering elements are not changed within a predetermined period an increased pressure drop may occur, which directly influences the increase of energy consumption.

The basis of proper maintenance of filtering components is to track their operation. For this purpose, it is necessary to increase or optimize the frequency of filter replacements. The maintenance procedures should involve regular filter inspections and, when needed, their replacements. It is advisable to install the filters containing a visible indicator of a condition of filtering element, and numerous systems have been developed for automatic registering and alarming that indicates that the pressure drop has exceeded the allowed value. An especially interesting possibility is the application of RFID technology where a filter is equipped with wireless communication RFID tag, which receives the pressure drop data from the differential pressure sensors which measures filter contamination and transmits a warning in the case that excessive contamination has occurred. Equipment maintenance personnel need not, in this case, to check for every individual filter but to carry an RFID receiver which receives the information about contaminated filter. Such system is under development at the Faculty of Technical Sciences in Novi Sad.

4.7 Designing the Overall System

The primary goal of a proper system design is to adjust the pressure, quantity and quality of compressed air to the needs of different users in their points of use. Although this can be a very simple task, complications are possible in cases when different end users have different or varying consumption needs. Two examples of the problems arising in systematic design are:

- one or multiple pressure levels within a system. Typical systems are designed to deliver the air according to the highest pressure and quality required by an end user. This approach can cause unnecessary expenses of energy if air prepared in such a way is required only by a small portion of consumers. The alternative solutions may be:
  – to build a system that delivers lower pressure and installs pressure amplifiers for those consumers that require higher pressure.
  – to provide and install dedicated compressor in the places of application for devices that require higher pressure.
- limiting the pressure variations. Inadequate control systems may produce large pressure oscillations which in turn consume an excessive amount of energy. When certain consumers have stochastic demand with respect to compressed air consumption, it is useful to install an additional reservoir close to those consumers in order to reduce pressure variations.

4.8 Optimization of Devices That Consume Compressed Air

Many devices that consume compressed air can be used in a more energy efficient manner. The optimization of devices that consume compressed air is one aspect of systemic approach to designing a compressed air system. The optimization can be achieved by:
- replacing the existing components with more energy efficient ones,
- installing additional elements, or,
- better use of the existing components.

For example, in the case of applying a vacuum generator, the savings in the compressed air are realized by using more energy efficient components, that possess an installed vacuum switch whose function is to save air (example is Air saving circuit – Festo). If the value of vacuum drops under a specified limit, the vacuum sensing switch sends a signal to vacuum generation and distribution components. In case the value of vacuum is within the designed range, the vacuum is not generated. Fig. 5 displays the operational diagram for vacuum pump and vacuum generator with implemented Air saving function.

Since the price of vacuum produced in this way is too high and vacuum suction elements represent significant consumers of compressed air, this option contributes to the increase of energy efficiency of the system. The savings are proportional to participation of time Δt, shown in Fig. 3, within a total time of holding the working object. This solution is especially suitable for application in which time of holding an object significantly participates in the total cycle of material handling.

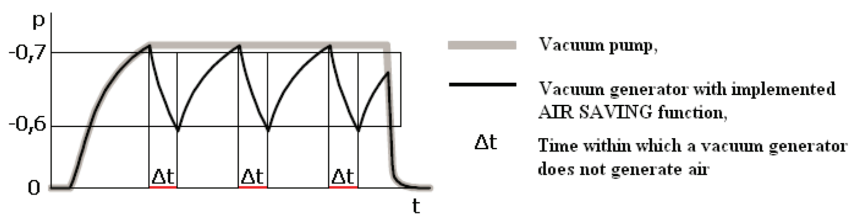

Fig. 3 Diagrams of operation for vacuum pump and vacuum generator

Using contemporary engineering tools for supporting the design of vacuum applications, it can be analyzed the change of system parameters or parameters of devices that are installed in the system. For example, by using the FESTO software for choosing and dimensioning vacuum components for manipulation of an object with a cylindrical shape whose dimensions are: diameter of 150 *mm*, height of 40 *mm* and weight of 200 *g*, a total of 6 vacuum suctioners was used whose diameter was 30 *mm*, with a standard shape, and a circularly distributed along the rim of the manipulated object. After entering the air pressure value of 6 *bars* that is present in the system, and selecting three vacuum generators that will supply the vacuum suctioners with the required amount of vacuum, a diagram is obtained as shown in Fig. 4. The maximum value of vacuum is obtained under working pressure of 5.4 *bar*. After changing the operating pressure value the diagram shown in Fig. 5 is obtained.

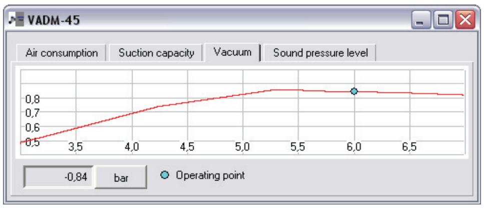

Fig. 4 The value of vacuum with the operating pressure of 6 bar

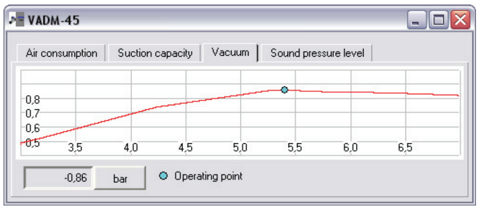

Fig. 5 The value of vacuum with the operating pressure of 5.4 bar

The change of operation pressure enables the usage of highest vacuum value, that is, the highest suctional capacity of vacuum suctioners. Air consumption, in the first case is 27.60 *l/min*, while under pressure value of 5.4 *bar* is 23.28 *l/min*. In these way savings of 4.32 *l/min*, or 0.072 *l/s* of compressed air are accomplished. If vacuum suctioners operate for 30*s* every minute, 8 *h/day*, 250 *days/year*, it is obtained a total suctioner operation time of 60.000 *min/year*, or 259.200 *l* of compressed air savings each year. This represents the savings for engagement of one group of vacuum suctioners for manipulating one working object on one work operation. The production processes often use a much larger number of vacuum suctioners. Therefore, the amount of compressed air that could be saved is significantly higher.

4.9 Reduction of Pressure Loses due to Pipeline Friction

Pressure loses in compressed air distribution network depend on several factors:

- topology (ring or network, etc.),
- geometry (pipeline diameter, curvature radius),
- materials used, etc.

The proper designing and realization of distribution network can optimize the friction loses. Regardless of the importance of network, a majority of the existing compressed air systems has non-optimal distribution networks due to various reasons:

- During the period of factory construction, the compressed air distribution network is often designed and installed by the companies that perform all other fluid related installation works. These companies are often poorly qualified for designing and installation of compressed air distribution network.

- Underdimensioned pipelines are occurring very often. Even the systems that were initially well-designed, become the "energy devourers" if the compressed air consumption is constantly increased and exceeds the level for which the system was initially designed.
- The lack of valves for interrupting the compressed air supply to the parts of the system being no longer in use or for machines that are not operated in second or third shift.

Since it is difficult and expensive to improve upon the existing network, proper designing and installation, which encompasses predictions for future system expansions, represent a significant factor for building of a good system.

4.10 Reduction of Air Leakage

Reduction of air leakage is probably a single most important measure for obtaining energy savings that are applicable to most systems. The awareness regarding importance of introducing regular leakage detection programs is on a very low level, partially because these spots are difficult to visualize and partially because they do not cause direct damage.

Leakages can lead to requirements for additional increase of compressor capacity and to increased compressor operating time. If pressure within a system drops below minimum level, the devices utilizing compressed air can be less efficient and equipment life cycle can be shortened, and in some cases breakdown of production lines may occur.

In typically well-maintained plants, leakages range between 2 and 10% of total capacity, but can amount up to 40% in the plants that are not maintained properly. It is considered that leakage can be tolerated while being less than 10% of total production. An active approach that involves permanent leakage detection and appropriate maintenance work can reduce the leakage to this level.

The causes of air leakages are:
- employees forgetfulness,
- poor system design and
- poor system maintenance.

Table 3 can serve as a guide in evaluating the scope of loses that arise due to leakage. In this example, it is assumed that the price of electrical energy is 0.1 *€/kWh* (costs of industrial electrical energy in EU average to 0,09 – 0,12 *€/kWh*) and that system is operated at 8 000 *hours/year*, while the price of compressed air preparation is 0,02 *€/m³*.

Table 3 Costs of compressed air leakages

Hole diameter		Air loss with 600 *kPa* (6 *bar*)			Annual production costs	Annual costs of production, preparation and distribution
Actual size	*mm*	*l/min*	*m³/h*	*kW* (approx.)	*€*	*€*
	1	80	4.8	0,4	320	768
	3	670	40	4	3,200	6,432
	5	1,857	111	10	8,000	17,827
	10	7,850	471	43	34,400	75,360

Removing leakage sources is based on detecting and repairing locations of leakage and removing the root causes that generated leakage within the system. Proper maintenance is of essential importance when fighting leakages and a good program for leakage detection can prevent unexpected failures from happening and reduce downtimes and loses.

Proper design and installation of network can eliminate leakage spots to a great extent, for example, with application of contemporary devices for condensate removal without air loss or by specifying high quality fast decomposing junctions. Awareness must be kept towards the fact that leakage continuously increases after completing repair work. The leakage is increasing with the same rate, regardless of whether the repair was done or not.

In many cases leakage is easily detected because large leakages are audible. Small and very small leakages are hard to detect and are hardly audible. In those cases, the elements of the system should be checked by some of the methods for leakage detection. The methods for detection of compressed air leakage are:

- leakage detection via sense of hearing,
- leakage detection via bubble release,
- ultrasonic detection and
- infrared leakage detection.

The most significant of all these methods is an ultrasonic method that utilizes a special detector that is shown in Fig. 6.

Fig. 7 shows the examples of operating the ultrasonic leakage detector, while Fig. 8 shows the detection of a leakage spot.

Fig. 6 The ultrasonic detector kit for Ultraprobe 100

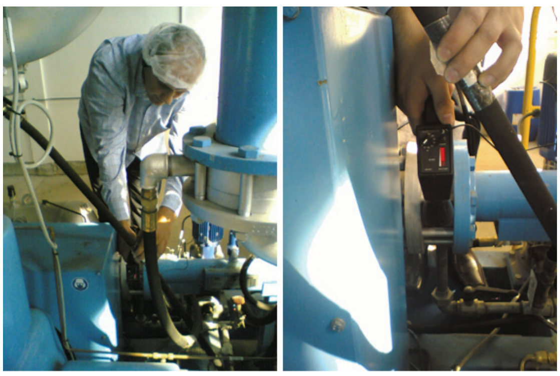

Fig. 7 Examples of utilization of ultrasonic detector

Fig. 8 Example of detected leakage spot

4.11 Reduction of Operating Pressure

Higher pressures increase leakage, and thereby the expenses. Usually, an increase of operating pressure is used to compensate for lack of capacity. The actual effect is quite opposite to the desired one. The higher the pressure, higher the leakage, while the irregular consumers consume more air, and thus more energy. Each 1 *bar* of the pressure increase is followed by an increase in electrical energy consumption required to compress the air in a range between 5% and 8%.

If the consumers are allowed to independently determine the amount of their need for compressed air, this system will never operate in an efficient manner, because everybody will be misled by the fact that they can obtain the pressure of any desired amount in any desired quantity. Higher air flow and higher pressure impose higher costs. The characteristic situation in which it is possible to solve this problem is one in which there is one or a small number of consumers in a requirement for higher pressure. In this case, it is suggested to install a secondary, smaller, high pressure unit or an appropriate amplifier (pneumatic booster), instead of operating the compressed air system of the whole factory on the higher level of pressure.

4.12 Unsuitable Applications of Compressed Air

Compressed air is extensively misused for applications in which it is not energy efficient, for which better solutions exist or, its implementation is incorrect in the places where its usage is justified.

Compressed air is the most expensive form of energy in a plant but its good characteristics, such as simplicity in application, safety of operation and availability in the whole plant area, often lead people to apply it even where more cost effective solutions exist. The users should therefore, always primarily consider the cost effective energy sources before applying the energy of compressed air. Table 4 gives examples of unsuitable usage of compressed air and alternative solutions that should be applied instead.

Table 4 Unsuitable applications of compressed air and alternative solutions

Unsuitable application of compressed air	Alternative solution
Control cabinet cooling	Ventilating, air conditioning
Cooling, aspiration, agitation, mixing, packaging blow-out	Blowers (customized compressors that produce compressed air in large quantities)
Vacuum production by Ventouri pipe	Vacuum pump or application of Ventouri's method with appropriate, energy efficient control
Cleaning of parts and processing residuals removal	Brushes, blowers, vacuum system
Removal of parts from the moving production line by nozzles	Blower, electrical actuator or pneumatic cylinder
Blower guns	Blowers, suctioners or application of reduced pressure air (installing the pressure regulators on guns or constructing low-pressure network)
Pneumatic tools	Electrical tools are more energy efficient although they have lowered torque control possibilities, shorter life time and are not inherently safe
Air knifes	High pressure blowers that are automatically turned off when cutting object is absent
Powdered materials transport (pneumatic transport)	Blowers
Vibrating the walls of powdered and granulated materials	Electrical vibrators

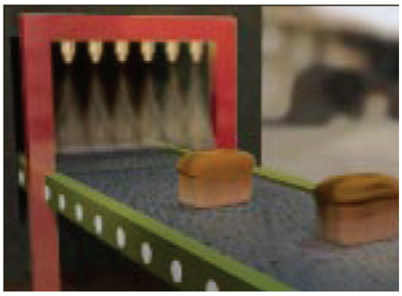

Fig. 9 Cleaning of bakery products with compressed air [16]

Fig. 9 shows an example of unsuitable application of compressed air. Nozzles are positioned above the line for bakery products in order to clean the product from the powder present and in order to cool it.

The nozzles themselves present an energetically unfavorable solution and an effort should be made to replace it with another solution. In this case, a fan could be used. Furthermore, if usage of nozzles is insisted upon, its more energy efficient version should be used.

Fig. 11 shows that nozzles are positioned too high so that a higher flow of compressed air is needed to accomplish the task, which means that for product of different heights the nozzle carrier frame height should be adjusted. Finally, it is necessary to set the active control over nozzles that will allow the air to flow based on sensor that signals the presence of a bakery product because Fig. 11 clearly shows that the air is flowing and that no bakery product is present beneath.

Other unsuitable uses of the compressed air involve unregulated consumers, supplying abandoned equipment or equipment that will not be used for a prolonged period of time, etc.

Unregulated Consumers

This covers all places of usage in which the compressed air can be directly released by opening a valve, all places where leakages are present, etc. For example, in applications with pneumatic tools, if the pressure regulator is not installed, the tool will use the full network pressure and this pressure might be significantly higher than the level required for its operation (for example, example 8 *bars* instead of 5.5 *bar*). Furthermore, this kind of pressure increase leads to greater equipment wear, which leads to greater maintenance costs and reduction of the equipment life cycle.

Abandoned Equipment

From time to time, reconstructions occur in factories that often lead to abandonment of some parts of the compressed air equipment leaving the air supply pipeline intact. The airflow going through the pipeline to the abandoned piece of equipment should be interrupted, as closely as possible to the air supply source, because it will inevitably generate some leakage and create unnecessary loses.

4.13 Recycling of Used Compressed Air

Pneumatic actuators are widespread in many branches of industry. It is a known fact that pressure inside the piston chamber can reach a final value that is equal to the supply pressure, only after some time after reaching at the end position of the cylinder piston. When the direction of the cylinder piston motion is reversed, all the compressed air contained within a working volume is released into the atmosphere. This represents a significant loss of the compressed air that possesses enough potential energy to perform some other kind of work. There is a possibility to reuse this kind of the compressed air [7], [17].

4.14 Measuring and Recording the System Performance

Measuring and recording the system performance, by itself, does not increase energy efficiency but usually presents a first step towards improvements in energy efficiency because of the two primary reasons:

- Measuring the air consumption and energy used for its production is of essential importance for determination, whether the changes in maintenance practice or equipment investments have justified their costs. As long as the price of a unit of consumed compressed air remains unknown, it is difficult to initiate the managerial processes necessary for improving the system.
- Recording the system performance is a valuable tool for discovering the degradation in performance or changes in quantity or quality of used compressed air.

Three basic parameters – airflow, air pressure and consumption of electrical energy, must be measured and recorded in order to evaluate the system performance. Although this might look simple, in principle, the interpretation of these data can present a difficulty [18], especially under conditions of variable consumption.

Measurement of flow of compressed air also involves certain technical problems and retrofitting reliable measurement instruments can be a difficult if not impossible task, unless it was taken care of during the phases of system design and installation. For example, most frequently used type of flowmeter must be installed into the pipeline sections that are free of turbulence and whose length must be 10 times greater than its diameter. In some systems, there is not an adequate place for installing of a flowmeter. Because of that, it is suggested that large systems and medium size systems must be designed and installed in such a way as to enable air flow measurements.

If the flow data is not available, the cheaper alternative equipment used for pressure measurement can be very useful to, for example, measure the pressure drop over filters or pressure loss along the pipeline, or for the purposes of detecting larger variations of pressure within the system.

5. The Potential of Applying the Measures for Energy Efficiency Increase

Measures for increasing energy efficiency of compressed air systems relate to different phases of the life cycle of a compressed air system:

- system design, gathering of offers or purchasing,
- system installation,
- significant changes in components or system improvement,
- preventive and corrective maintenance.

The greatest potential for achieving the savings exists in times of conceiving a new system because at that moment a great spectrum of energy saving measures, described in Table below, is available. This kind of situation is relatively rare, because new factories are not continuously built so that even the best opportunity for systematic design becomes rarely available (first column in table 5). Table 5 gives approximate indications of the phases in which each of described measures can be applied.

Much frequently encountered is the case of replacing the main components of the existing system. In this kind of situation, it is possible to implement many measures, some of which are faced with greater difficulty especially the ones that are related to system design:

compressed air distribution network, systems with multiple pressure levels, selection of the type of end consumer, etc. It is estimated that the possibility for savings in the existing systems, in the time of replacement of main components, amounts to 2/3 of the efficiency increase that could be realized in a new system that would be designed with initially having energy efficiency in mind [10].

Table 5 The applicability of energy saving measures in specified phases of a compressed air system life cycle [10]

	System design, acquisition	Installation	Component replacement	Maintenance
Improvement of drives	++		++	+
Optimal choice of compressor	++		+	
Sophisticated control system	++		++	
Recuperating waste heat	++		++	
Improvement in air treatment	++		++	++
Overall system design	++		+	
Optimizing end use devices	++		+	
Reducing frictional losses	++	+	+	
Reducing air leaks	+	+	+	++
Measuring system performance	++		+	++

Some measures for energy savings can be implemented into the existing systems in any moment. These are, for example, implementation of sophisticated control systems or waste heat regeneration. The procedures related to maintenance and system operation, especially the frequency of filter replacement, represents one of the main sources for energy savings. These measures can also be implemented at any time during a life cycle of compressed air system components.

Table 6 gives the estimate of applicability of these measures based on opinion of the larger number of experts [11]. Only the estimates of the average savings in relation to most significant measures for increasing energy efficiency are given, given that the return of investment time is less than 3 years.

Table 6 The expert's estimate of the average energy savings for compressed air systems in relation to most significant measures [11].

Energy saving measures	Applicability %		Gain %	Potential contribution
	From – to	Average		
Reduction of overall system requirements	20 – 40	30	20	6.0
Match compressor and load	5 – 15	10	3	0.3
Improvements of compressor control	15 – 40	25	10	2.5
Improvement of compressor components	5 – 20	15	5	0.8
Operation and maintenance	50 – 85	75	10	7.5
Total savings				17.1

Table 7 Detailed estimates of the applicability of energy saving measures for a compressed air system [10].

Energy saving measures	(1) Applica-bility %	(2) Gains %	(3) Potential contri-bution %	Comments
System installation or refurbishment				
Improvement of drives (high efficiency motors)	25	2	0.5	Most cost effective in small (<10 *kW*) systems
Improvement of drives (speed control)	25	15	3.8	Applicable in variable load systems. In systems containing multiple compressors only one needs to be installed.
Upgrading of compressor	30	7	2.1	
Use of sophisticated control systems	20	12	2.4	
Recovering waste heat for use in other functions	20	20	4.0	The gain is accomplished as an energy gain and not the consumption of electrical energy because it is transformed into useful heat.
Improved cooling, drying and filtering	10	5	0.5	This does not involve more frequent filter replacement (see below)
Overall system design, including the multi-pressure systems	50	9	4.5	
Reducing frictional pressure losses (for example by increasing pipe diameter)	50	3	1.5	
Optimizing certain end use devices	5	40	2.0	
System operation and maintenance				
Reducing air leaks	80	20	16.0	
More frequent filter replacement	40	2	0.8	
		TOTAL	32.9	

LEGEND:
(1) % of CAS where this measure is applicable and cost effective
(2) % reduction in annual energy consumption
(3) Potential contribution = Applicability * Reduction

REMARK: Potential for saving 32.9% is less that the sum of the savings for individual measures. The total possible savings must be calculated as a more complex formula that is not presented here.

Much more detailed estimate that involved a group of experts estimated the applicability of energy saving measures and potential gains based on application of those measures is given in [10]. The experience has shown that industrial companies are not willing to allocate precious capital resources into investments related to energy savings, even if they show high rates of capital return. Because of that a cut-off point of 36 months is chosen for determining the economic of investment. It is the highly conservative approach because it provides a profitability of over 25%, which is significantly higher than the average rate of industrial investment's profitability. Table 7 shows the results obtained.

6. CONCLUSION

Compressed air systems represent a significant segment of production and service systems. Therefore, it is necessary to pay attention to their energy efficient operation. The application of the measures for an energy efficiency increase in compressed air systems enables prolongation of the components' life cycle and the reduction of total operation costs that in turn increases the economic quality of working process. The procedure that was presented and explained in detail, containing cost effective activities illustrated with appropriate examples, can significantly increase the energy efficiency of compressed air systems.

Acknowledgement: *The paper is part of the research done within the project of the National Program of Energy Efficiency entitled "Increase of Energy Efficiency of Pneumatic Systems in Industry" (EE-232016), financially supported by the Ministry for Science and Environmental Protection of the Republic of Serbia.*

REFERENCES

1. Šešlija, D., Lagod, B.: The State of Pneumatic Systems in the Industry of Serbia from the Aspect of Energy Efficiency, Centre for automation and mechatronics, Novi Sad, 2006.
2. Šešlija, D.: Systemic Approach to Pneumatic Systems Management, 28. Conference with international participants HIPNEF 2002, str. 185-190, Vrnjačka Banja, 02-04.10.2002.
3. Stojiljković, M., Seslija, D, Golubovic, Z., Blagojevic, V.: *Increase of Energy Efficiency of Pneumatic Systems in Industry,* Plenary lecture on 21st International Congress of Process Industry Procesing 2008, Subotica (2008).
4. Seslija, D., Stojiljković, M., Golubovic, Z.: *Increase of Energy Efficiency in HIPNEF Systems,* Introductory Report on 31st Congress with international participation HIPNEF 2008, pp. 3-15, Vrnjačka Banja (2008).
5. Dudic, S., Golubovic, Z., Seslija, D., Stojiljkovic, M.: *On the Filtration of Compressed Air in an Energy Efficient Pneumatic System,* Proceedings of 21st International Congress on Process Industry PROCESING 2008, Subotica (2008).
6. GPG385, Good Practice Guide: Energy efficient compressed air systems, British Compressed Air Society Ltd, for Carbon Trust,United Kingdom,: February 2005.
7. Blagojevic, V., Stojiljkovic, M., Seslija, D., Golubovic, Z.: *Increase of Energy Efficiency of Compressed Air by Energy Renewal,* Proceedings of 21st international congress on process industry PROCESING 2008, Subotica (2008).
8. Blagojevic, V., Stojiljkovic, M., Seslija, D., Golubovic, Z.: *Thermographic Identification of Leakage Spots in Pneumatic Systems*, Proceedings of 21st international congress on process industry PROCESING 2008, Subotica (2008).
9. Ignjatovic, I., Seslija, D., Golubovic, Z., Stojiljkovic, M.: *Pneumatic Systems Audit – a First Step Towards Increase in Energy Efficiency,* Proceedings of 21st international congress on process industry PROCESING 2008, Subotica (2008).

10. Radgen, P., Blaustein, E. “*Compressed Air Systems In The European Union*“, Energy, Emissions, Savings potential and Policy Actions, LOG_X Verlag GmbH, Stutgart, 2001.
11. ****Assessment Of The Market For Compressed Air Efficiency Services*, prepared for Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory by XENERGY, Inc. Burlington, Massachusets U. S. Department of Energy, 2002.
12. Šešlija D.:Production, preparation and distribution of compressed air, IKOS, Novi Sad, 2002.
13. Šešlija D.: Compressed air quality in contemporary automatized systems, *12th international conference INDUSTRIAL SYSTEMS IS ‘02, Collected papers,* Vrnjačka Banja, 22-23.10.2002, pp. 158-163.
14. Mitrović, Č., Golubović, Z., Šešlija, D.: Implementation, significance and effects of filtration in industry, Research and design for industry, ISSN 1451-4117, UDC 33, 12 (2006) IV, Belgrade, Serbia. pp. 13-20.
15. Golubović, Z., Šešlija, D., Milovanović, B., Majstorović, B., Vidovic, M., The Challenges in Sterile Pressurised Air Preparation, BAM-CX.2007, Nr. 2295-2315, *Proceedings of PAMM – Conference*, Balaton Almadi, Hungary, June (2007) pp. C152-153/2007.
16. Energy Saving - The Norgren guide to saving energy in compressed air systems, www.norgren.com
17. Blagojević, V., Stojiljković, M.: Mathematical and Simulink Model of the Pneumatic system with Bridging of the Dual Action Cylinder Chambers, Facta univesitaties, series Mechanical Engineering Vo5., N^{0}1, Univerity of Niš, 2007, pp. 23-31.
18. Šešlija, D., Odri, S., Tešić, Z., Stankovski, S.,: Bridging the Gap Between Machine and Production Control System, Facta Universitatis: Series Mechanical Engineering, Vol. 3, No. 1, 2005, pp 81- 92.

IDENTIFIKACIJA MOGUĆNOSTI POVEĆANJA ENERGETSKE EFIKASNOSTI SISTEMA VAZDUHA POD PRITISKOM

Dragan Šešlija, Miodrag Stojiljković, Zoran Golubović, Vladislav Blagojević, Slobodan Dudić

U radu se prezentuju osnove menadžerskog pristupa radi povećanja energetske efikasnosti sistema vazduha pod pritiskomi. Identifikuju se mogućnosti povećanja efikasnosti proizvodnje, pripreme, distribucije i racionalne potrošnje vazduha pod pritiskom kao i načini na koji se oni mogu da primene radi povećanja energetske efikasnosti.

Ključne reči: *energetska efikasnost vazduha pod pritiskom, filtriranje vazduha pod pritiskom, RFID*