

RISK ASSESSMENT AND RISK REDUCTION MEASURES FOR ELECTROPNEUMATIC EQUIPMENT

DOI: 10.5937/EMC26071J

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ABSTRACT

This paper presents a risk assessment related to the use of an electropneumatic educational set intended for laboratory teaching. The risk assessment was conducted in accordance with the ISO 12100 and ISO 14121-1 standards, based on risk analysis through defining machine limits, hazard identification, and risk evaluation. Mechanical, electrical, thermal, ergonomic, and other hazards that may arise during the use of the electropneumatic educational set were identified. A risk matrix was used as the risk assessment method to quantify risk levels before and after the implementation of risk reduction measures, and to perform risk evaluation. Based on the assessment results, technical, organizational, and personal protective measures were proposed, with particular emphasis on user-implemented measures, including the development of safe work procedures, operator training, the use of personal protective equipment, and organizational safety measures. The results show that, after applying the proposed measures, all risks are reduced to an acceptable level, confirming that the use of the electropneumatic educational set in a laboratory environment is safe when the prescribed safety measures are consistently applied.

Key words: Risk assessment, risk reduction, electropneumatic equipment.

INTRODUCTION

The development of modern industrial and educational systems increasingly involves the integration of pneumatic, electrical, and control components, which significantly enhances functionality but at the same time introduces new potential sources of risk to user safety. Electropneumatic systems are now widely used in industry, as well as in educational institutions, where they serve as a fundamental tool for acquiring practical knowledge in the fields of automation and mechatronics.

The safety of machines and work equipment represents one of the key requirements in both industrial and educational environments. The European Machinery Directive 2006/42/EC, along with corresponding national regulations and international standards, clearly defines the obligation to conduct risk assessment as a fundamental step in ensuring the safe use of machines and technical systems. According to ISO 12100 and ISO 14121-1 standards, risk analysis includes a systematic identification of all hazards that may arise throughout the machine life cycle, as well as an assessment of the probability and severity of possible consequences. The definition of general rules and safety requirements for pneumatic systems and their components, in accordance with ISO 4414, contributes to reducing the risk of failures and injuries. Previous research indicates that ANSI guidelines emphasize the identification of tasks and hazards that had not previously been considered, particularly those related to maintenance [Eherton, 2007].

The critical need to improve machine safety represents a strategic framework for risk mitigation through effective hazard identification, risk assessment, and implementation of control measures [Li et al., 2025]. Therefore, considering that the electropneumatic educational set is used under laboratory

conditions while working with students, it is necessary to conduct a detailed risk analysis that includes the examination of all mechanical, electrical, and thermal hazards, as well as harmful effects caused by noise and vibrations, in addition to ergonomic and organizational aspects of work. The aim of this paper is to carry out a risk assessment related to the use of an electropneumatic educational set through risk analysis and evaluation. After identifying hazards in all relevant phases of the life cycle, it is necessary to perform risk assessment using a risk matrix and, after implementing measures for risk reduction, determine the magnitude and acceptability of the residual risks.

ELECTROPNEUMATIC EQUIPMENT

The electropneumatic educational set is laboratory equipment that enables practical learning of electropneumatics, a field that integrates pneumatics—through pneumatic components (control of single-acting and double-acting cylinders and valves (2/2, 3/2, 5/2, etc.) using compressed air, pressure regulators, filters, and connectors with electrical engineering and automation through electrical components (control of components by means of electric current, sensors, switches, relays, PLC controllers, indicators, and actuators). Pneumatics is used in performing manufacturing operations such as drilling, turning, milling, sawing, forming, and others, as well as for general material handling methods including clamping, moving, positioning, orientation, and material flow distribution. Figure 1 shows the electropneumatic educational set and the diagram of pneumatic components. The diagram schematically presents: Power components (cylinders, motors, visual indicators), Control elements (directional control valves), Process elements (control and non-return valves, pressure control valves, timers, sequencers), Input elements (valves, switches), and Supply elements (compressor, reservoir, service unit, and pressure regulation valves). Pneumatic tools and operational components can be loaded up to the stall point and are therefore protected against overload.



Figure 1: Electropneumatic educational set and diagram of pneumatic components

RISK ASSESSMENT

Risk assessment consists of risk analysis and risk evaluation. Risk analysis is carried out through determining the machine limits, hazard identification, and risk estimation, while risk evaluation determines whether the risk has been adequately reduced. According to ISO/TR 14121-2:2012- Part 2: Practical Guidance and Examples, risk assessment methods include: hazard identification using checklists, risk matrices, risk graphs, numerical scoring, quantified risk evaluation, and hybrid methods. Hazards identified on the electropneumatic set during the testing phase and operational process, according to the Rulebook on the Method and Procedure of Risk Assessment in the Workplace and Work Environment, are: Mechanical hazards arising from the use of work equipment, hazards associated with workplace characteristics, hazards arising from the use of electrical energy, harmful effects occurring during the work process (noise, vibrations, radiation, materials/substances) and harmful effects resulting from psychological and psychophysiological strain causally related to the workplace and tasks performed by employees (ergonomics).

Risk matrix

The risk matrix is one of the methods used for risk assessment and is applied after risk analysis has been carried out, that is, after hazards have been identified. The risk matrix represents one of the most commonly applied risk assessment methods and is used after the completion of risk analysis, namely after the identification of all relevant hazards. This method enables the assessment of risks associated with machines and equipment in various industrial fields. The primary purpose of the risk matrix is to enable the ranking of identified risks according to their magnitude, in order to clearly distinguish those that are unacceptably high and for which risk reduction measures must be implemented. In this way, the risk matrix serves as a tool for decision-making regarding risk acceptability and for determining priorities in the implementation of preventive and protective measures. Its advantages are reflected in its simplicity, speed, and efficiency of application, making it suitable for practical use in industrial environments. The following Table 1 presents the risk assessment performed using the risk matrix method, as well as the measures for risk reduction. Risk evaluation was also carried out in order to determine whether the risk was adequately reduced after the implementation of the proposed measures.

Table 1: Risk assessment using the risk matrix method

Operator / Task	Hazard	Initial Risk Assessment			Risk Reduction Measures	Risk Assessment After Measures			Status (Acceptable)
		Severity	Probability	Risk Level		Severity	Probability	Risk Level	
Testing and operation	Mechanical (kinetic energy): moving cylinders, crushing	3	4	12 High	Restricted work zone, training	3	2	6 Moderate	Y
	Mechanical: uncontrolled cylinder start	4	3	12 High	Lockout procedure, signaling, supervision	4	2	8 Moderate	Y
	Mechanical – hose rupture (pressurized fluid impact)	3	3	9 Moderate	Regular hose inspection, pressure limitation	3	1	3 Low	Y
	Electrical – direct contact	4	2	8 Moderate	24 V DC voltage, proper cables, prohibit. of live work	4	1	4 Low	Y
	Electrical – indirect contact	3	2	6 Moderate	Grounding, installation testing	3	1	3 Low	Y
	Thermal – hot compressor surfaces	2	3	6 Moderate	Warning signs, safe distance	2	1	2 Low	Y
	Compressor and exhaust noise	2	3	6 Moderate	Maintenance, PPE if required	2	2	4 Low	Y
	Vibrations	2	2	4 Low	Stable installation, maintenance	2	1	2 Low	Y
	Substances – compressed air, dust	2	3	6 Moderate	Ventilation, proper connections	2	2	4 Low	Y
	Ergonomics	2	2	6 Moderate	Adjustable table height, breaks	2	2	4 Low	Y
	Slipping, tripping, and falling	3	2	6 Moderate	Organize cables, mark walkways	3	1	3 Low	Y

Risk matrices have been in use for many years and have been developed in various forms, such as 5×5 matrices, as well as matrices defined by standards and guidelines, including ANSI B11 TR3:2000 and IEC 61508. The differences among them are reflected in the number of levels and the method of defining risk factors, with four-level and five-level matrices being the most commonly used in practice. For each identified hazard or hazardous situation, it is necessary to assess the severity of the possible consequences. In addition to the severity of consequences, the probability of occurrence of a

hazardous event is also evaluated for each hazard. Based on the conducted risk assessment using the risk matrix method, it can be concluded that the initially identified risks associated with the operation of the electropneumatic educational set were predominantly classified within the categories of moderate and increased risk, particularly in relation to mechanical and electrical hazards. After the implementation of the prescribed technical, organizational, and personal protective measures, all assessed risks were reduced to an acceptable level. No risk remained within the high-risk category, confirming that the electropneumatic educational set is safe for use under laboratory conditions, provided that the defined protective measures are consistently applied.

REDUSTION OF RISK

Measures for the prevention, elimination, or reduction of risks are determined based on the assessed risk, in accordance with occupational safety and health regulations, technical regulations, and standards, and are aimed at achieving risk reduction. The Figure 2. shows the decomposition diagram of measures for risk reduction.

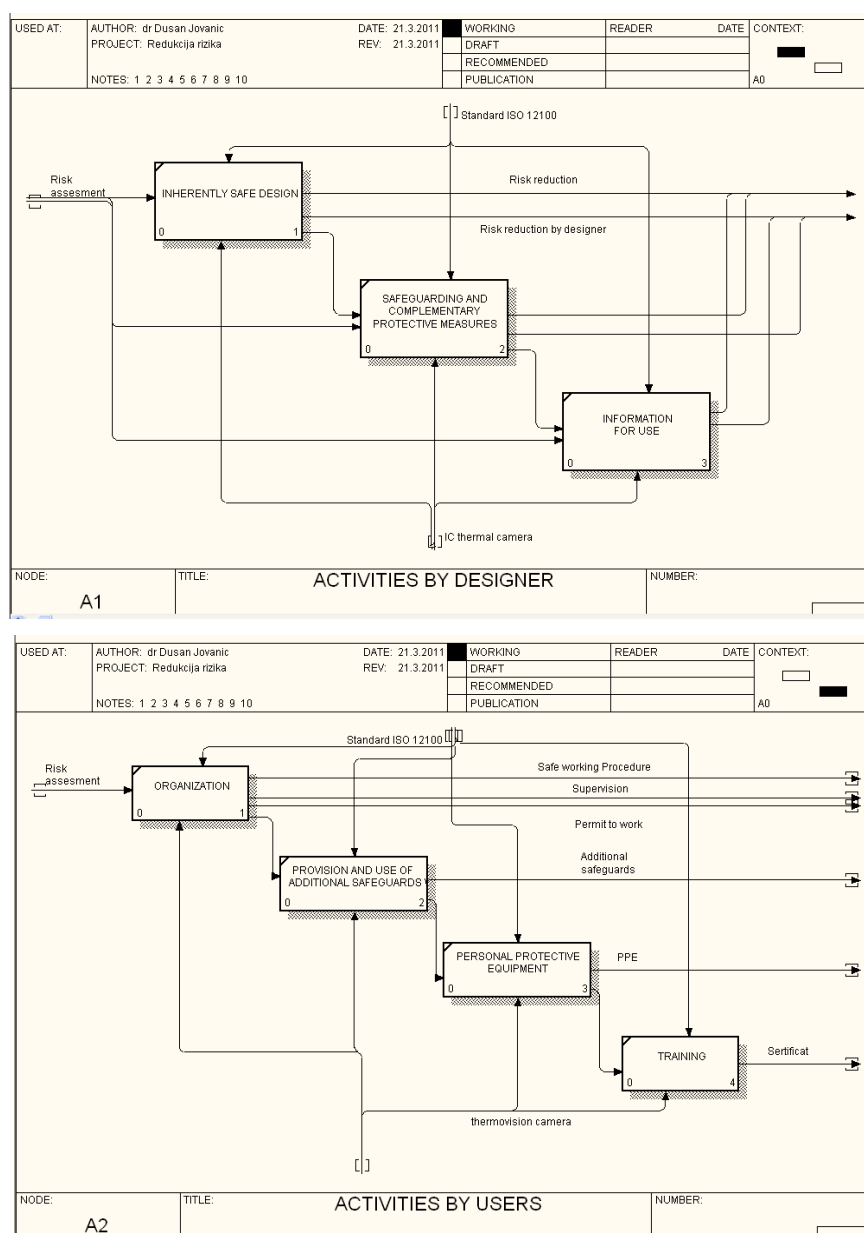


Figure 2: Decomposition diagram of activities by designers and users

The activity tree of the risk reduction is shown in Figure 3.

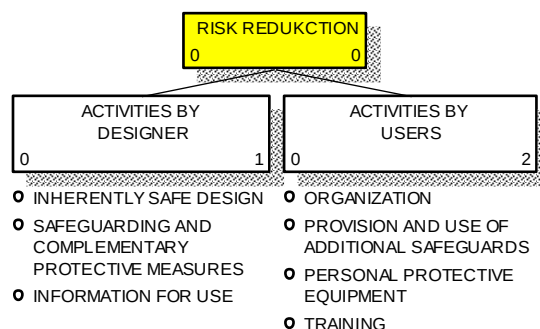


Figure 3: The activity tree of the risk reduction

Instruction No.	02/2026	Device	Electropneumatic Set	Manufacturer	Festo	Type	TP101
General Rules: Use of the equipment by untrained (unqualified) personnel is prohibited							
Disconnect the power supply before changing connections. Do not touch moving parts or electrical contacts during operation. Air pressure must be shut off and released from the system before maintenance. Never increase the pressure above 6 bar. Do not operate the system if there are loose or damaged connections. In case of an electrical fault, immediately disconnect the power supply.							
Measures to Be Taken Before Starting Work							
Check that the compressor is functioning properly and that the filters are operational. Gradually increase the pressure to the operating level and check for leaks. Check pressure gauges, valves, and regulators for correct readings. Verify that all mechanical components are properly installed (cylinders, valves, sensors). Visually inspect pneumatic hoses to ensure they are: in good condition (without cracks, bends, or damage), firmly connected and secured, positioned so they do not interfere with moving parts. Check electrical connections: cables must be insulated and undamaged, connectors must be properly connected and labeled. Check that sensors and solenoid valves respond correctly. Connect the 24V DC power supply and verify grounding. Ensure there are no visible traces of oil, water, dirt around connections, or fumes from components (in electropneumatic systems). Verify the presence of signs, labels, and diagrams (they must be legible and in place).							
Measures to Be Taken During Operation							
Safe Start-Up: Before starting, ensure that no one is standing within the operating area of the cylinder or moving parts. Use an audible/light signal before starting the system, if possible. Start the system slowly, gradually increasing the load.							
Operating Guidelines: Do not exceed the maximum pressure and voltage values. Do not use unsuitable media (air with excessive moisture or impurities). Do not manually stop or obstruct cylinder movement — use the designated blocking valves. Adjust cylinder movement speed using regulating valves, not by sudden changes. Avoid vibrations and hammering effects that may cause material fatigue.							
Safe Shutdown / Stopping: Use designated valves for safe shutdown (air flow blocking). Release pressure from the system before accessing components. Disconnect the electrical power supply (for the electropneumatic section).							
Measures to Be Taken After Completing Work							
Disconnect the power supply. Shut off the air supply. Release pressure from the system. Properly store and arrange the equipment.							
Warning Signs							
							
Mandatory Signs							
							
Prohibition Signs							
							
 Phone: Procedure in Case of Accident, Failure, or Damage:							
Date	20.12.2025.			Prepared by:	Dr Dušan Jovanić		

Figure 4: Safe work procedure

The measures undertaken by the manufacturer for risk reduction include: Inherently safe design, Guards and complementary protective measures, and Information for use (information, operating instructions, warnings). Risk reduction measures implemented by the user include: Organization

(procedures for safe work, supervision, work permits), Provision and use of additional protective measures and guards, Use of personal protective equipment (PPE), Training, Inspection and testing of work equipment, Maintenance etc.

The risk reduction measure applied by the user in terms of organization is the preparation of a procedure (instruction) for safe operation, presented in Figure 4. In addition to general information and technical characteristics of the electropneumatic educational set, the instruction also describes the measures that should be undertaken before, during, and after operation, as well as hazard, prohibition, obligation (PPE), and first aid signs.

CONCLUSION

The risk assessment of the electropneumatic educational set was carried out through risk analysis and evaluation. The risk estimation was performed using the risk matrix method. It was determined that the highest risks originate from mechanical hazards related to the kinetic energy of cylinder movement, in particular uncontrolled movement of cylinders and the accumulated potential energy associated with hose rupture and the resulting impact of pressurized fluid, as well as electrical hazards due to direct contact. After the implemented risk reduction measures, including the definition of a safe work procedure, as well as the risk evaluation, no risks remain in the increased-risk category. The highest remaining risk is related to mechanical hazards caused by uncontrolled cylinder movement, with a moderate risk level. Most risks have been reduced to a low level. It can be concluded that the operator's activities when working with the electropneumatic educational set are not considered high-risk work, provided that the prescribed safety measures are followed, appropriate training is ensured, and regular supervision and maintenance of the equipment are carried out.

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