

# Artificial Education Process Environment for Electro-Pneumatic System

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**Abstract**—This paper explains the basic methods of troubleshooting, maintenance and diagnostic of pneumatic and electro-pneumatic systems in the case of a flipper machine as an artificial industrial environment for educational purposes. The article deals with operation and servicing of industrial electro-pneumatic equipment and control systems, and shows methods how to avoid common mistakes and inefficiencies. In addition to the historical overview and practical application, hardware and software design procedures are also presented.

**Keywords**— pinball, electro-pneumatic, training, maintenance, troubleshooting, diagnosis, PLC, flipper

## I. INTRODUCTION

The predecessor of pinball machines was the so-called "bagatelle", a game of French origin, which was developed in France in the 1700s. During the game, players used cues to push the ball on a slightly tilted table with holes, similar to billiards. Nails were placed in the table, on which the ball could bounce back. This is where the English name of pinball machines used to this day, "pinball", comes from. Different holes meant different point values. The goal of the game was to score the most points.

In 1871, Montague Redgrave, an English-American inventor, built a bagatelle table in which the ball was shot into the playing field by a spring rather than pushed into it with cues. There were no flippers to push the ball back, the player had to tilt the table itself [1].

During the Great Depression, many people wanted cheap entertainment, which is why coin-operated pinball machines became popular. In 1931, David Gottlieb launched the game with the fanciful name of "Baffle Ball". He sold more than 50,000 of the machine, making his company the world's largest pinball machine manufacturer.

The first pinball machine using electric elements was made in 1933. The machine shot the ball back from one of the holes using an electrified coil, and signaled the bonus points to the player with an electric bell. Not long after, all manufacturers installed light bulbs on their machines.

Pinball machines for bouncing the ball first appeared in 1947, on a machine with the fanciful name "Humpty Dumpty" manufactured by the Gottlieb company. Instead of the usual one pair today, there were three pairs of pinball machines, which were placed on top of each other in the playing area. The first two-pinball machine was also a Gottlieb product, the "Triple Action", with the flippers facing outwards. "Just 21" was published in 1950, which already had a layout similar to today's.

In the 1970s, with the advent of microprocessors, the previous electromechanical relay control of pinball

machines was replaced by printed circuit boards. Digital displays and speakers playing sound effects also appeared on the machines. The first such machine using a microprocessor is linked from Gottlieb to the excellent manufacturer Bally in 1932. [2]

In the early 1980s, the popularity of pinball machines declined significantly due to the rise of video games. Manufacturers tried to make their machines more interesting with as many visual and sound technical elements as possible, but sales did not start to rise until the early 1990s. At that time, video game sales fell due to the spread of PCs, and pinball machines became popular again in arcades. It was around this time that movie and series themed machines appeared and spread, e.g.: "The Addams Family", "Indiana Jones: The Pinball Adventure" and "Star Trek: The Next Generation".

By the end of the 1990s, most of the big manufacturers went bankrupt and new, smaller manufacturers started to appear. The most recent innovation on the machines was the appearance of LCD displays, which spread with the fancy name "New Canasta" machine of the MarsaPlay company. [3]

Although pinball machines have undoubtedly lost their popularity, they have been a permanent fixture in arcades since their appearance. The cult of pinball machines that is still alive today is well symbolized by the fact that there are pinball museums in several places around the world, including in Budapest. For 38 years now, the pinball exhibition "The Pinball Expo" has been held in Chicago, where interested parties can admire and try out the most modern and significant types.

### A. Pneumatic pinball machines

Apart from the example presented in the article, only two pneumatically operated pinball machines are known. One such machine was made in the United States for educational purposes. It was built by students in a high school, mostly with available tools and parts. The machine is more like the old machines without flippers. Instead of flippers, it is possible to push the ball back using compressed air. It has an extremely simple structure, contains very few game elements, and no scoring system at all.

Dutch engineer Daniel de Bruin built a factory-quality electropneumatic pinball machine. The machine can implement complex functions, using multiple game elements and sensors. It is interesting that it contains many transparent elements made of plastic glass, which is why most of the moving mechanisms are visible. It differs from traditional machines in that the various actuators, such as elevators and track switches, must be operated by the player using dedicated levers and buttons.

## II. PINBALL DESIGN STEPS

Games like pinball helps students to learn programming and hardware development and also enable them to immediately gain feeling of success and further motivation. The project provides students knowledge and skills for working in industrial environments with electro-pneumatic machines and programmed controllers. [4]

Designing game related machines teach creativity, artistic skills, problem solving skills and teamwork skills. Students are motivated to learn the details of hardware and software components, because they find fun to play with the machine. Students also learn to handle hybrid electronics circuits, mechanisms, embedded systems, industrial control systems, communication protocols, sensors and actuators. [8]

Pinball games offer single-player and multi-player modes. In traditional single player mode, with a predefined shot sequence need to be make, to win the game. It is unexciting for expert players, as a solution, the sequence of shots needed to win the game required to base on the gameplay, thus each play could be different. [9]

In traditional multi-player mode the players take turns alternately, in this case the regular player need to wait more for the more expert players turn. Maximizing the play time for the players per turn is a solution. [10] For more exciting gameplay, the players can influence the other players game. [11]

In multi-player mode, players can play cooperatively (against the game), or competitively (against each other). Game specific actions can be made, like change the slopes or gates, turn on or off the functions, modify the scoring system, change the lighting. State diagram of the multi-player mode can be seen on Fig.1. The player related game opinions are stored in software, in an array.

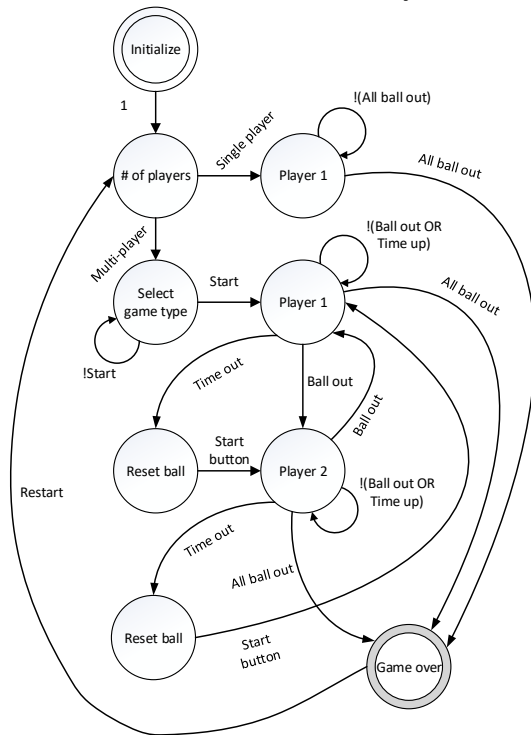


Figure 1. Multi-player mode state diagram

## III. HARDWARE AND SOFTWARE IMPLEMENTATION

### A. Flipper components

The sensors placed on the playing area, send a signal to the controller [12-14]. Most of the time, we come across deformation contacts, which actually consist of two thin plates, isolated from each other in the default position. When a force of the right direction and magnitude is applied, the plates make contact and close a circuit. Deformation contacts can fulfill several functions. There are some on which the ball rolls almost unhindered, these are the so-called "rollover switches".

Among the deformation contacts are those connected to some track element, such as the "slingshot". When the contacts close, the tension lever moves forward. The tension arm pushes the rubber forward, making it tighter and allowing the ball to bounce off it at a higher speed. This solution is necessary because if the tire were in such a highly stretched state all the time, it would wear out sooner.

In addition to these, there are also contacts with which the ball comes into direct contact, these are called "targets". The target boards have a more robust construction than the other contacts, because the ball has to bounce back from them, which means serious stress. The part in contact with the ball is usually made of plastic, which is attached to the metal sheet during injection molding.

The functioning of mushrooms is also based on a similar principle. Before the ball hits the support structure shown in the middle, it depresses a ring that is connected to a plate-deformation contact. The contact activates a current-carrying coil that is positioned vertically relative to the game table. The iron core moved by the coil is connected via a rod to the upper, metal plate-shaped ring of the mushroom, which thereby moves downwards. The design of the ring is such that the ball slides on its inclined surface. As a result, when the ring moves down, it shoots the ball sideways. The spring that returns the iron core to its initial position also moves the upper ring of the mushroom back to the upper position through the rod.

The launcher can mostly be operated mechanically, i.e. manually by the player, as well as automatically. The pinball machine also implements the so-called "multi ball", i.e. the bonus ball function with the launcher.

### B. Hardware realization

In this project the various actuators are not moved by current-carrying coils or mechanical structures, but pneumatically, working cylinders operate both the launcher and the flippers. The multi ball system it is realized mechanically, with the help of a neodymium magnet and a working cylinder. Point counting is assisted by the deformation contact from factory pinball machines.

The ideal length/width ratio of the table is around 1.8. Easy portability was also the goal of the design, the size of 720x405 mm proved to be adequate. The furniture board seemed to be the right choice for the material of the prototype table due to its smooth surface and easy workability.

The design was aided by 3D modeling software, which made it easier to place the court elements (seen on Fig.2.), it was immediately visible how much space must be left between the court elements in order for the ball to fit.

Modeling helps to think through and plan moving parts and their operating mechanisms [15], e.g. in the case of

pinball levers. The parts were produced using 3D printing technology (seen on Fig.3.).

The ball ejector is a 12 mm bore diameter, 50 mm stroke, double actuation cylinder, it was chosen because of its compact size and relatively long stroke. Moving the pinball leavers was also solved with a pneumatic cylinder with a bore diameter of 12 mm, their stroke is 25 mm.

5/2 diverter valves were used to control the bistable working cylinders in the equipment, and 24 V direct voltage is required for their operation (seen on Fig.4.). The pressure of the supply air can be adjusted on the compressor, and can be regulated separately on the individual working cylinders with the help of the choke-check valve fittings.

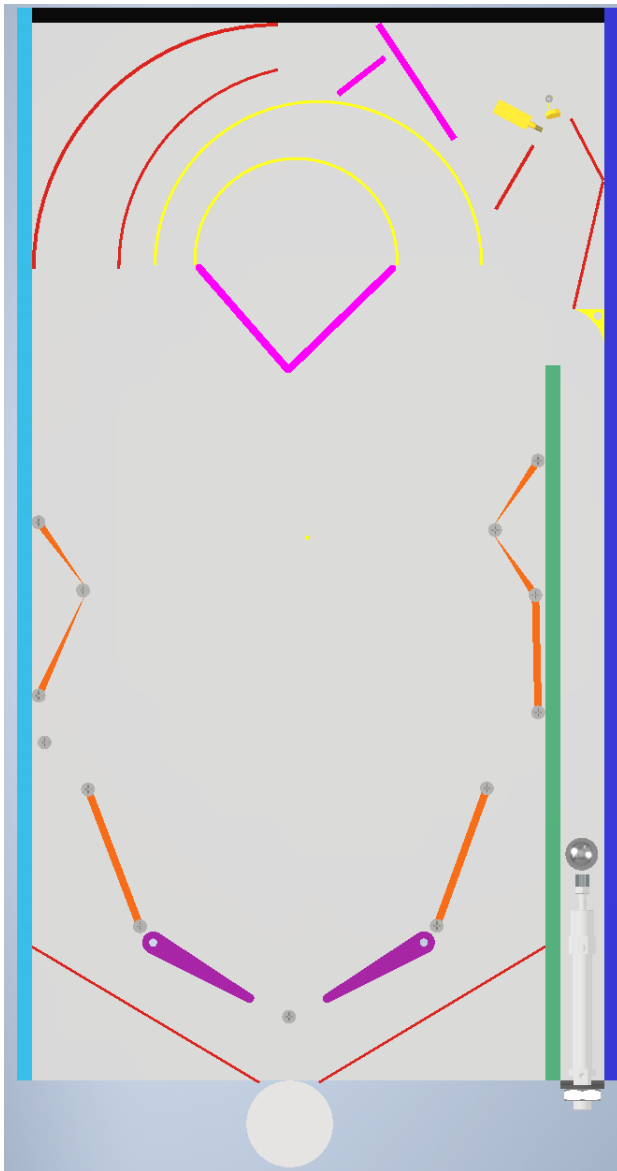


Figure 2. 3D model of the machine under development



Figure 3. 3D printed pinball lever prototype (1. flipper arm, 2. flipper arm axis, 3. arm attached to pinball arm axis, 4. the link connecting the cylinder axis and the flipper arm)

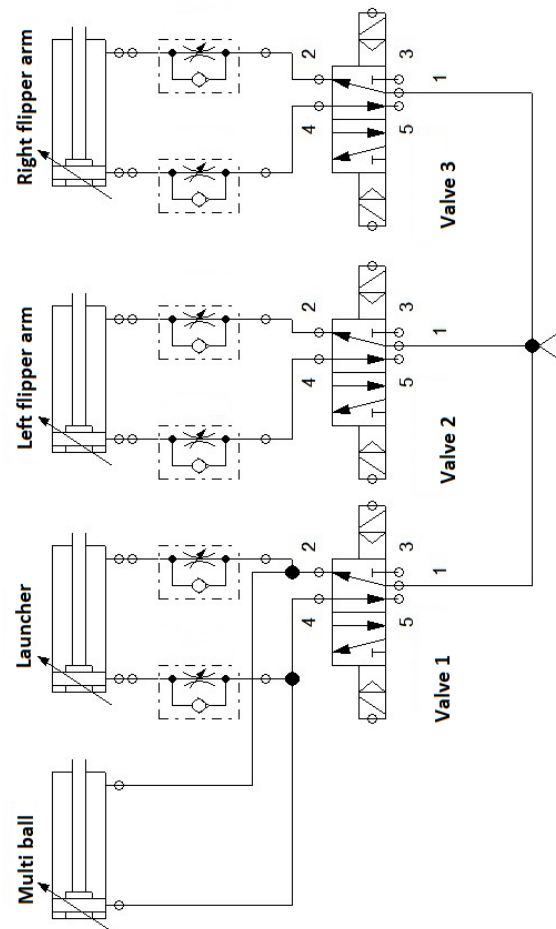


Figure 4. Pneumatic circuit diagram

A 4 mm thick plexiglas sheet was placed on top of the machine, its role is to prevent the ball from flying out (seen on Fig.5.). The game table of pinball machines tilts at  $8^\circ$  towards the player, increasing the slope allows for a more dynamic gameplay.



Figure 5. Structure of the table

### C. Software elements

The control of the built pinball machine is solved by a PLC, in order to create an artificial industrial environment that supports education [16, 17].

The primary elements of the point counting system are the sensors placed in the playing area, the wires coming from here are connected to the ports configured as inputs on the controller [18, 19]. The valve island is controlled via the ports configured as outputs of the PLC (seen on Fig.6.).

| Device Name | Device Name      | Device Name | Device Name          |
|-------------|------------------|-------------|----------------------|
| X000        | LaunchButton     | Y000        |                      |
| X001        |                  | Y001        |                      |
| X002        | LeftButton       | Y002        |                      |
| X003        |                  | Y003        |                      |
| X004        | RightButton      | Y004        | LauncherActivate     |
| X005        |                  | Y005        | LauncherRetract      |
| X006        | LeftTrackSensor  | Y006        | LeftFlipperActivate  |
| X007        |                  | Y007        | LeftFlipperRetract   |
| X010        | RightTrackSensor | Y010        | RightFlipperActivate |
| X011        |                  | Y011        | RightFlipperRetract  |
| X012        | GameStart        | Y012        |                      |
| X013        |                  | Y013        |                      |
| X014        |                  | Y014        |                      |

Figure 6. Programming the inputs and the outputs of the PLC

The push button that operates the pinball levers pushes the working cylinder out each time the button is pressed and can even be held outside.

The task of the point counting system is to convert the signals of the sensors into point values. In order to ensure correct detection, debouncing is solved by software. This ensures that the ball is hit once, and points are added once.

The display of point values and other variables can be set in the Haiwell Cloud Scada Designer software, after setting the communication port number, the exact type of PLC, the name of the variables to be displayed, and the display parameters. and takes place with the help of the Haiwell Cloud Scada Runtime software. When the Haiwell Cloud Scada Runtime software is running, the parameterized

interface is displayed on the HMI or PC monitor (see on Fig. 7.).



Figure 7. Displaying point values

## IV. TROUBLESHOOTING METHOD OF ELECTRO-PNEUMATIC SYSTEMS

Pneumatic and electro-pneumatic circuit diagram interpretation and understanding component functionality is necessary for effective working [20]. Following a logical approach to fault finding enables a quick problem solving [21]. Eliminating unnecessary checks and component replacements reduces service time, cost and downtime[22]. During maintenance a fine adjustments optimizing the system performance [23], improves quality and component lifetime. [24]

At troubleshooting keeping the manuals and schematics on hand is useful, just like in other industries [25, 26]. A good manual contains service guides, service history, common problems and useful tips. A proper schematic contains the default working parameters for example airflow rates, timing, motor speed, cylinder stroke lengths and machine performance, and also the modifications during the machine's lifetime. The understanding of the system and how the subsystems and the components of the machine are interrelated is essential.

When working on electro-pneumatic equipment, the conditions for safe work must be kept in mind. At a visual inspection of the machine with disconnected electricity and pressure, any loads that are not mechanically locked down should also be secured.

In troubleshooting it need to determine what is happening or what is not happening in the machine. How long has this been going on? Was the failure sudden or gradual? The problem exists immediately after startup or somewhere mid-cycle? It is proposed to contact with the machine operator and check the maintenance records.

When testing the operation, it is necessary to monitor which components of the equipment are under pressure and what physical displacements they are capable of achieving. When handling electrical circuits, it is important to make sure of the type of electrical voltage (AC/DC) and level (5 V, 24 V, 230 V, etc.). Check that liquids have not shorted out connectors, also check for wear or tear of wires, or for twisted cables.

Under visual inspection a frayed, burst, worn or pinched hoses, worn or extruded seals, loose or chattering components are also can be an indication of faults. Check also for excessive air or fluid leaks and erratically movements.

A malfunction in one subsystem could be interrelated to the other parts of the machine, e.g. a clogged air filter [27, 28]. Testing one subsystem at a time will reduce the diagnostic area [29, 30], still safety must be kept in mind. Any disconnected lines and ports should be plugged under sectioned operation to prevent contamination and unwanted functionality.

The root cause of the fault may not be obvious at once, each of the potential causes need to be checked. Change only one thing at a time between testing iterations, start with the most probable ones. Proposed to check lubricant and its drip rate, also check actuator alignment.

After finding the root cause of the problem a repair of a replace need to be done. The decision is hardly dependent on to the allowable downtime, parts and labor costs, and available repair options.

Reporting is a vital element of troubleshooting. Recording the problems, remedial actions, and updating changes connected to a machine is very useful for the future work.

#### A. Example for the troubleshooting method

A typical pneumatic system starts with a filter regulator and a lubricator also valves, actuators, fittings, pipes and other miscellaneous components are part of the system. For correct operation proper air pressure is also essential. Faulty valves, when the valve do not open or close properly, can cause pressure drops.

Regulators are also desired to control the air pressure. A failing regulator causes inconsistent air pressure, as a consequent, the machine cannot operate in working order. Measuring pressure with a gauge is a useful diagnostic tool.

When water molecules (vapor) entering to pneumatic systems, it can cause rusting and wearing. Under extreme cold, water can freeze in the components, and cause mechanical stress and damage. Oil droplets and mechanical particles are also can cause clogging and block airflow. To preventing these issues, it is proposed to regularly check the filters, and replace or clean contaminated ones.

As an example: while a double-acting air cylinder is exhausted, there should be no air exhausting out through the exhaust port of the previous two position control valve. Once the cylinder has fully extended, the air that was exhausting out of the two position control valve exhaust port, should now have stopped. If the air continues to exhaust out of the exhaust port, it is probably that the actuator has a faulty gasket in the cylinder, and it causing the air to bypass the piston and go out still through the exhaust port.

The air coming out of the exhaust port so it looks like the valve is leaking. The simplest way to check it, is to disconnect the air pipe from the valve, and if there is air leaking from the cylinder air pipe, the actuator has a faulty gasket, otherwise the valve is the faulty component.

The troubleshooting process is the same for the other end position of the cylinder piston. If the cylinder is fully retracted, there should be no exhaust air coming out of the previous control valve. If there is still air coming out of the

valve exhaust port, once again, the troubleshooting method should be repeat, to find out which component is faulty.

The following list summarizes the main troubleshooting steps in the case of an electro-pneumatic system:

- safety considerations,
- determine the problem,
- understand the machine,
- visual inspection,
- see the malfunction in action,
- isolate subsystems,
- test the subsystem,
- repair the causes of the malfunction,
- test the subsystem,
- test the system,
- paperwork.

#### V. CONCLUSION

This paper aimed to show practical solutions for troubleshooting, maintenance and diagnosis of pneumatic and electro-pneumatic systems. The shown artificial industrial environment is a flipper machine, which solves educational purposes. The article describes the relationship between the system hardware and software components, also dealing with design possibilities. Special tools and methods can be used for dealing with pneumatic cylinders, pneumatic and electro-pneumatic valves, sensors, electronics, industrial controllers, and further components. The proposed problem solving tools and methods are well applicable in real-life situations.

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