

Development and Application of Manufacturing Automation

CONTROL AND AUTOMATION (ACMA5001)

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1.Introduction

The history and development of control systems represent a fascinating journey through human ingenuity and technological innovation. From ancient mechanisms devised to regulate the flow of water or control the temperature of furnaces to modern-day automated systems orchestrating complex industrial processes, the evolution of control systems reflects our relentless pursuit of efficiency, precision, and mastery over the forces of nature.

This report will discuss the development and progression of the three recognised types of manufacturing automation: fixed, programmable and flexible automation. It will investigate the advantages and disadvantages of these systems and the industries/scenarios in which they may be used.

This paper also provides an overview of each automation type. Specifically, it focuses on how a flat-packed furniture company could use flexible automation and why this would be the best type for the industry.

2.Automation History

A control system can be defined as “an interconnection of components forming a system configuration which provides a desired system response” (Sathiyaraj, Balasubramaniam, 2018 p.229-248). Early man created the first tools in the prehistoric era to harness and focus their physical strength onto the surroundings. This evolved into machinery that allowed man to harness the power from the environment, such as windmills and water wheels. These machines are some of the earliest examples of automated systems. (Shah, S. 2020) Control systems can be open or closed; an open system has no feedback loop and runs on a fixed parameter. For example, a remote-controlled light switch would be an open system; the on button would signal the light to turn on, but the remote does not know if the light has turned on and has no built-in error correction. Another example of an open control system would be a standard kitchen toaster; the toaster energises the heating element for a pre-set time but has no feedback loop and doesn't know how toasted the bread is. Closed control systems incorporate a feedback loop and can, therefore, adjust the output according to a set parameter. A simple example of a closed control system would be a fan oven; the user inputs a temperature, for instance, 200 degrees Celsius, and the heating element is energised; a thermocouple inside the oven will continuously read the temperature and feed this back to the control system, once the target temperature is reached the system will turn off the heating element and when the temperature drops the control system will re-energise the heating element. (Bennett, 1993)

Open control systems are cheaper and require less maintenance than closed control systems, but both are used in industries. Even though open control systems have no feedback loop, they can be used in some situations.

Heron, the great mathematician, physicist and engineer, invented many automated systems, including a device invented around 30 AD that automatically opened and closed the giant doors at the entrance to places of worship. Heron named this invention “Machine Number 37”. (Bennett, 1993): This marvel of ancient times worked by the priest lighting the fire in the morning; this heat was transferred into the air within a brass sphere with some water. The rising air temperature would increase the pressure within the sphere, forcing the water through a pipe into a hanging pot. The

pot would be attached to a pulley system that, in turn, opened the giant doors. This process took a few hours, but it amazed the people at the time. (Shah, S. 2020)

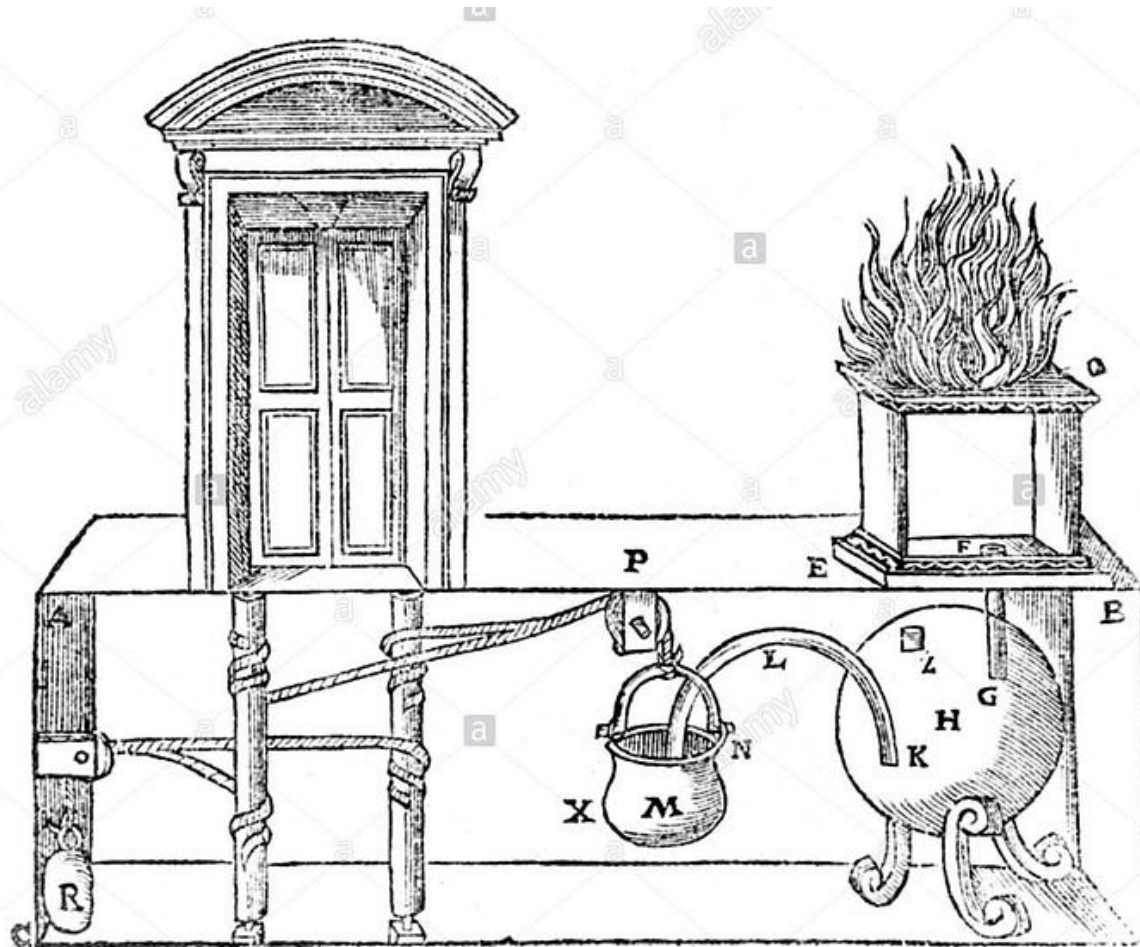


Figure 1 Diagram of Machine Number 37 (Shah, S. 2020)

Automated processes have existed since Ancient Greece, and during the Industrial Revolution, they rapidly evolved from simple thermodynamics and fluid dynamics to more complex chemical reactions, such as the lambda sensor used in automotive engines to control the air-fuel mixture. A lambda sensor works by the oxygen in the exhaust fumes reacting with the zirconia ceramic sensor; this reaction generates a small voltage across the sensor, and the voltage changes non-linearly according to the level of oxygen present. (Shah, S. 2020)

During the 1620s, Cornelius Drebbel, a Dutch inventor, created what is widely considered the first feedback control system; he made an oven for hatching eggs that was temperature controlled. He did this by incorporating a mercury float connected to a system that adjusted the flame and the heat applied to the oven. As the temperature in the oven rises, the float softens the flame and reduces the temperature. Similarly, as the temperature in the oven decreases, the float would lower, allowing the flame to heat the oven.

During the Industrial Revolution, many machines were powered by some sort of steam engine; these steam engines relied on safety devices such as pressure relief valves, which allowed the system to release energy from the boiler or pipework if the pressure became too high. Some of the first pressure relief valves worked by a weight being applied to a lid, and when the force of the steam pressure became higher than the weight force on the lid, the hinge opened and released some pressure.

For closed-loop control systems to work, sensors must monitor and react to changes in some properties, such as heat, pressure, distance, luminance, etc. Today, a wide array of sensors and control systems are used. Much research has been done to help understand the output from these sensors. James Maxwell published a paper on the stability criterion for 3rd-order systems in 1868. A 3rd-order control system is a dynamic system whose behaviour is described by a 3rd-order differential equation; this was extended to 5th-order systems by Edward Routh in 1877 and moved onto nonlinear systems by Alexander Lyapunov in 1892. Control system theory states the order of a system is determined by the highest derivative of its governing differential equation (Ogata, 2009).

Three-term controllers, commonly known as PID (Proportional-Integral-Derivative) controllers, are widely used in control systems for managing industrial processes, mechanical operations, and various other applications where precise control is essential. The PID controller operates by combining three distinct types of control actions: proportional, integral, and derivative, which work together to minimise the error between a desired setpoint and the actual process variable. The proportional part of the controller produces an output that is proportional to the current error value; the error value is the difference between the desired setpoint and the measured value

from the sensor. The integral section integrates the past errors; this helps eliminate steady-state errors but can lead to overshoot and instability. Lastly, the derivative section of the controller considers the rate of change of the errors and, therefore, can anticipate future errors and apply damping to improve system stability and reduce overshoot. These accurate and reliable control systems allow companies to manufacture high-precision parts in massive quantities with rapid turnaround times due to the precision and speed of the sensors used. (Ogata, 2009) These advancements in stability led to engineering breakthroughs such as stability control in aircraft, ships and missiles.

3.Modern Automation

Plant and Block diagrams visually represent a system with sensors and feedback loops so the engineer/ technician can easily understand why a particular outcome may occur. The plant segment of the visual refers to the system or process that is being controlled. The block section describes the control parameters and the relationships between the components. They are used alongside process and instrumentational Diagrams (P&ID) in the chemical industry. The P&ID will outline the pipework, valves, and instrumentation locations and connections, but the Plant and Block diagram will outline the logic and feedback loops that the sensors send back to the control room.

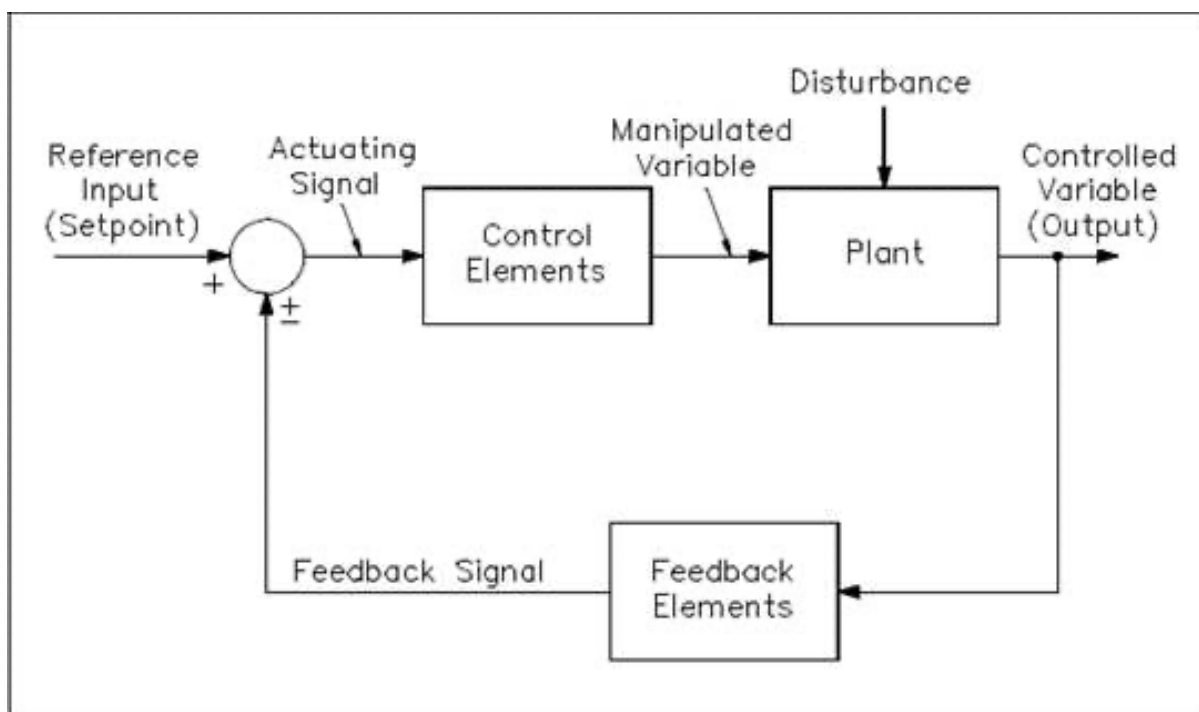


Figure 2 Plant and Block template (Technology Transfer Services, 2024)

A modern chemical plant usually has an on-site and remote-control room. This is done by using programmable logic controllers (PLC). These PLCs are used like individual computers that take in the electrical information from sensors, perform a calculation by the PLC programme, and then output a signal to another device, such as a control valve, to adjust properties such as flow rate, temperature, etc.

The PLC logic is visualised in a ladder diagram. This simple-to-read workflow allows users to follow a process and see what sensors give readings and output to what devices. (Ogata, 2009)

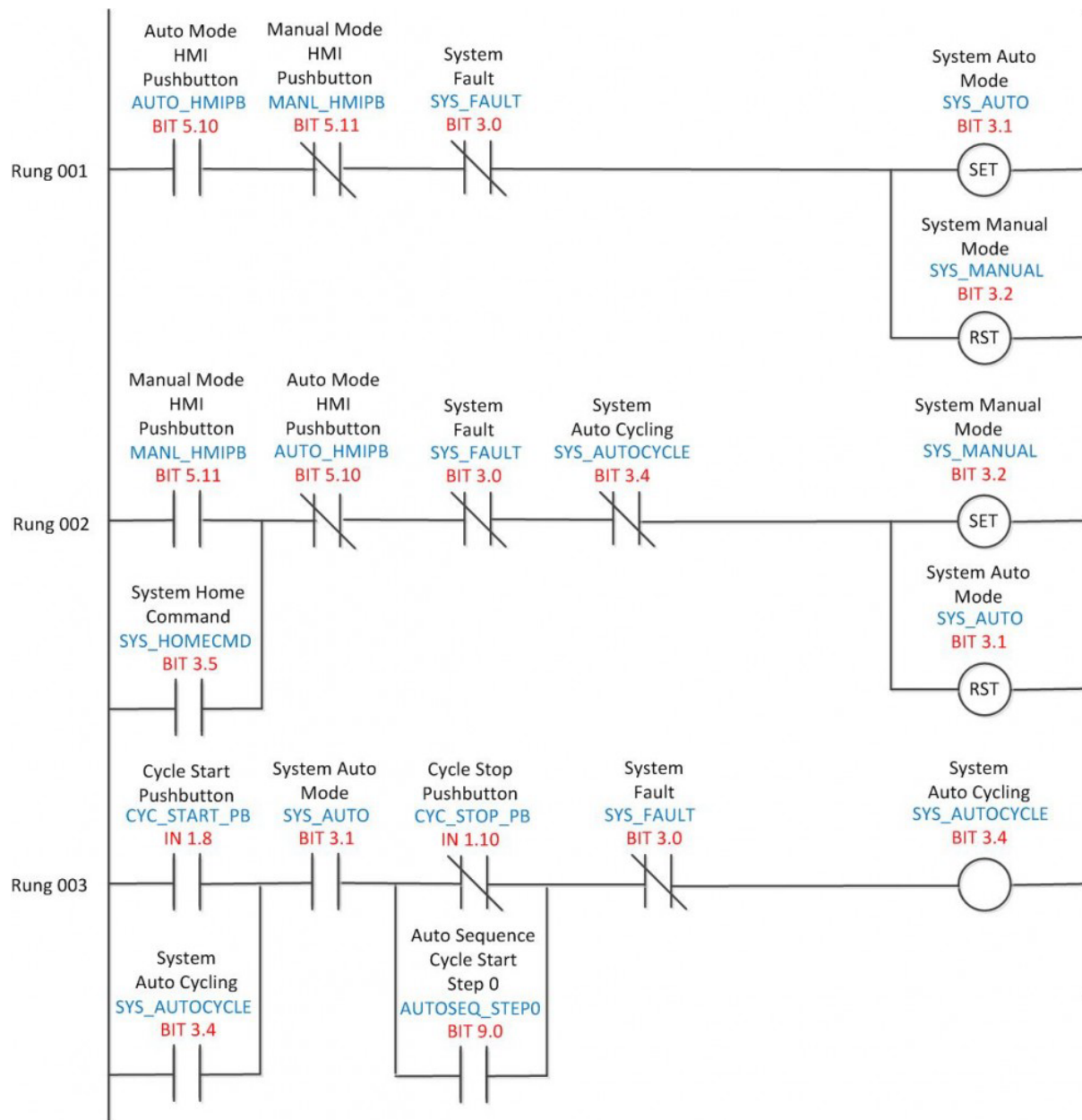


Figure 3 PLC Ladder diagram example (Automation Primer, 2024)

4.Automation Types

4.1 Fixed Automation

An automation process is fixed if the tooling or manufacturing process is unchangeable and set for the specific product and process. A fixed automation process usually requires a high initial investment and a long-term plan to produce the product.

A fixed automated process modified for a slightly different product would require some manufacturing overhaul. Chemical production plants incorporate a fixed automated assembly line; the factories are set up to produce the chemical product, and the process will remain the same over time.

Industrial companies are not the only industries using fixed automation; industries such as mobile phone manufacturers would also use fixed automation. They will still use complex computerised machines designed and set up to produce a specific component or assemble a particular smartphone. When these companies release a new design, they tend to cease production on an older model and utilise this footprint to produce the new design.

4.2 Programmable Automation

Programmable automation is a 21st -century development that allows the process/ operation to be modified on commands from a programme/ workflow. This quick and seamless process modification will enable companies to manufacture similar products. Computer Numerically Controlled (CNC) workshops run on a programmable automated workflow, as the machines can be seamlessly uploaded with the relevant G Code for the appropriate component. Another example of this type of manufacturing would be personalised celebration cards; these online stores operate by people purchasing stock birthday/ event cards and uploading a personalised message that is run through a program and printed onto the desired card.

4.3 Flexible Automation

Flexible automation is similar to programable automation, but instead of a program making the modifications, the workers would adjust the manufacturing process as required by the product.

Many manufacturing companies are moving to flexible automation as production machines become increasingly reliant on and integrated with computers and robotics. This allows companies to offer a broader range of products and designs and be more competitive.

A company incorporating flexible automation would require machines and tools that can easily be adjusted and are not pre-set up for a specific product. Flexible automation can be seen in companies that need to be able to produce a variety of products and quantities.

4.4 Automation Comparison

Fixed, programmable, and flexible automation solutions all have pros and cons. For example, fixed automation systems are optimised for specific tasks. They are, therefore, extremely efficient and consistent, but this comes with a trade-off for a lack of flexibility and the ability to modify the process. Fixed automation usually has a high initial investment and a limited product range.

Programmable automation is moderately flexible and cost-effective, as the process can quickly adapt to a new product with a program modification or software update. However, the reliance on software and technical hardware can cause downtime due to bugs, glitches, and internet outages. In some instances, technical support for specific equipment may be limited. (Groover, 2020)

Flexible automation is, by its name, adaptable and easily modified for various products or processes. This helps increase efficiency and lends itself to being easily scaled up with a business as it grows. Reconfiguring flexible setups can take time and money; initially, configuring a factory/ process for flexible automation comes with high costs and possibly long lead times.

In summary, each type of automation has its advantages and disadvantages, and companies need to carefully compare these and select the right type for the industry. (Groover, 2020)

5. Case study

This report section analyses why flexible automation is the most appropriate method for a flat-packed furniture company.

Flat-packed furniture companies often use CNC laser cutters and robotics machines to move large pieces of wood or other building materials. Assuming the company has a vast array of designs and products it needs to produce, it would likely employ a flexible system in the workshop or factory. This would allow the company to easily switch between production of various designs as required by the customer orders. As all the designs would be made from similar materials, the same toolset, such as CNC routers and lasers, could be used for each design. The worker would need to load up the correct design to the computer system and load the machine with the appropriate materials from the warehouse.

Unlike fixed and programmable automation, flexible automation would help the company quickly scale its manufacturing as the business grows. Just-in-time manufacturing can be achieved with the use of flexible automation. This is where the manufacturer will produce the item in line with the customer's order rather than having a warehouse stocked with premade products. This allows companies to save money on storage and focus on manufacturing and innovation. (Groover, 2020)

If fixed automation were used, the company would need a separate area to produce each product, limiting the product range and vastly increasing the time between new designs being sent to customers. This is comparable to how motor car manufacturers operate; they invest a large sum into a production plant for a single design or component, such as an engine or specific car. This is one of the reasons motor companies have 4-5 years in between new car releases.

Flexible automation would also allow the flat-pack company to produce new designs quickly and even aid them in prototyping designs, as all the tools are easily adjusted. Flexible automation can easily be scaled up or down for small businesses or large industry leaders. (Groover, 2020)

In conclusion, flexible automation offers the ideal solution for flat-packed furniture manufacturers. It enables them to meet the demands of a dynamic market, efficiently

produce a diverse range of products, and deliver customised solutions while maintaining high levels of productivity and cost-effectiveness.

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