Engineering Systems

A system is an assemblage of components or elements intended to act together to accomplish an objective. Nothing in nature can be completely isolated from everything else, so we see that our selection of the boundaries of the system depends on the purpose and limitations of our study. Almost everything can be considered a system at some level.

The view of a system as a set of interconnected elements is what has been called the "systems approach" to problem solving. With this approach, the analysis focuses on how connections among the elements influence the overall behavior of the system. Its viewpoint implies a willingness to accept a less detailed description of the operation of the individual elements in order to achieve this overall understanding. This viewpoint can be applied to the study of either man-made or natural systems. It reflects the belief that the behavior of complex systems is made up of basic behavior patterns that are contributed by each element and that can be studied one at a time.

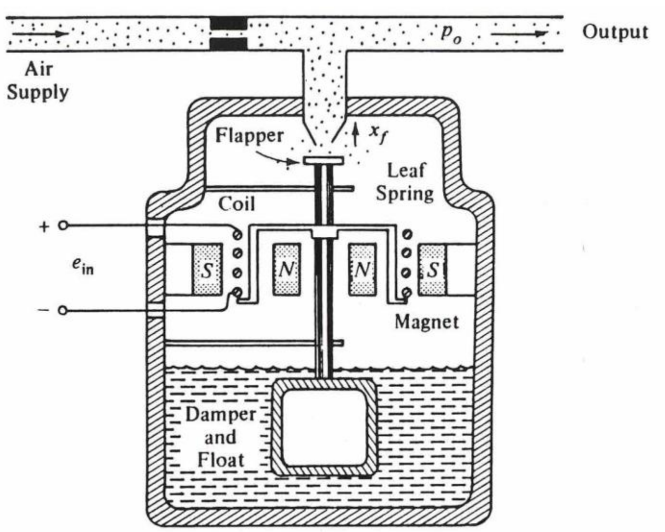
The behavior of an element is specified by its input-output relation, which is a description – usually mathematical – of how the output is affected by the input. An input is a cause; an output is an effect due to the input. Thus the input-output relation expresses the cause-and-effect behavior of the element. The system itself can have inputs and outputs. These are determined by the selection of the system's boundary. Any causes acting on the system from the world external to this boundary are considered to be system inputs. Similarly, a system's outputs can be the outputs from any one or more of the elements, viewed in particular from outside the system's boundary.

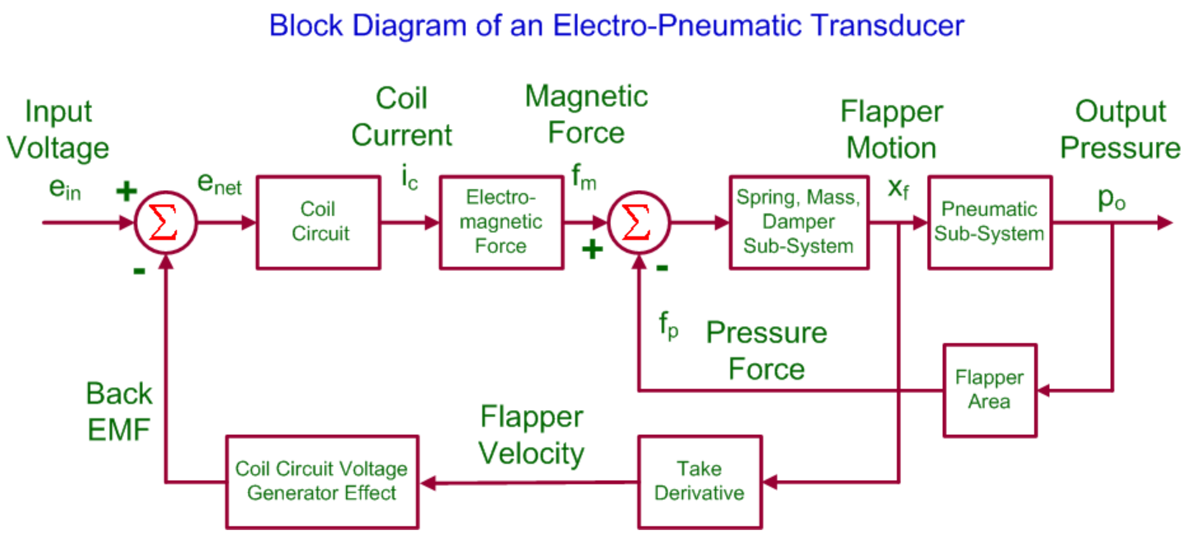
There are two types of elements or systems: static and dynamic. A static element or system is one whose output at any time depends only on the input at that time and which responds instantaneously to the input at that time. It is an approximation, an idealization, as nothing is instantaneous in the real world. As an example, consider the simple electrical resistor. You are familiar with Ohm's Law which says that the electrical voltage e applied across the resistor is proportional to the current i flowing through it, i.e., $e = iR$, where R is the constant of proportionality called resistance. When the applied voltage is constant, this equation describes the physical situation quite well. But when the applied voltage is changing with time, it predicts that the current will change instantaneously proportional to the applied voltage. That is not possible, as we have said, and hence this law is an approximation, although a very good one, when used in a situation where the applied voltage is changing with time. A dynamic element or system is one whose present output depends on past inputs. Consider an automobile. If one were to turn off the engine when driving, the car's position would continue to change because of the car's velocity due to past inputs from the engine. A static system contains all static elements. Any system that contains at least one dynamic element is a dynamic system.

In the study of dynamic engineering systems, we deal with entire operating machines and processes rather than just isolated components and we treat the dynamic behavior of mechanical, electrical, magnetic, fluid, thermal, and combined systems. We strive to emphasize the behavioral similarity among systems that differ physically and develop general analysis and design tools useful for all kinds of physical systems. This serves as a unifying foundation for practical application areas. In our desire for physical insight, we often sacrifice detail in component descriptions so as to be able to better understand the behavior of complex systems. This also allows us to better design and optimize complex systems, as we are using as few essential parameters as possible in the system description. We use methods which accommodate component descriptions in terms of experimental measurements when accurate theory is lacking or too complex and develop universal lab test methods for characterizing component behavior. It is common practice that as components are built or purchased, they are tested to determine accurate parameter values needed for overall system design.

Engineering dynamic systems can be small-scale and large-scale. Two examples of engineering dynamic systems are discussed below (*System Dynamics*, E. Doebelin, 1998). However, the techniques we will develop are also applicable to ecological, biological, and economic dynamic systems.

First, consider the electro-pneumatic transducer, a picture and schematic of which are shown. A transducer is a device that transforms one type of energy to another. In this case, electrical energy is transformed into fluid energy. This is a dynamic engineering system and it has long been used to provide regulated air pressures for the control of process systems. Industry today is demanding far greater accuracy of its pneumatic control systems and so this has become an even more important component. The purpose of this device is to accept an input voltage signal e_{in} in the range 3-15 volts and produce a closely proportional output air-pressure signal p_o in the range 3-15 psig. It allows the electrical system that is connected to this device at the input to "talk" to the pneumatic system connected to this device at the output. This engineering dynamic system has mechanical, electrical, magnetic, and fluid elements.



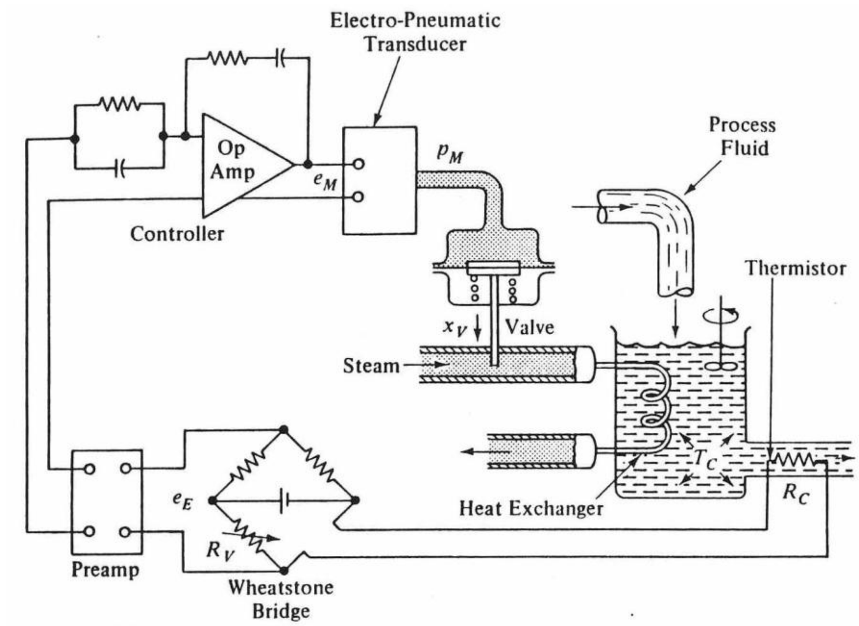


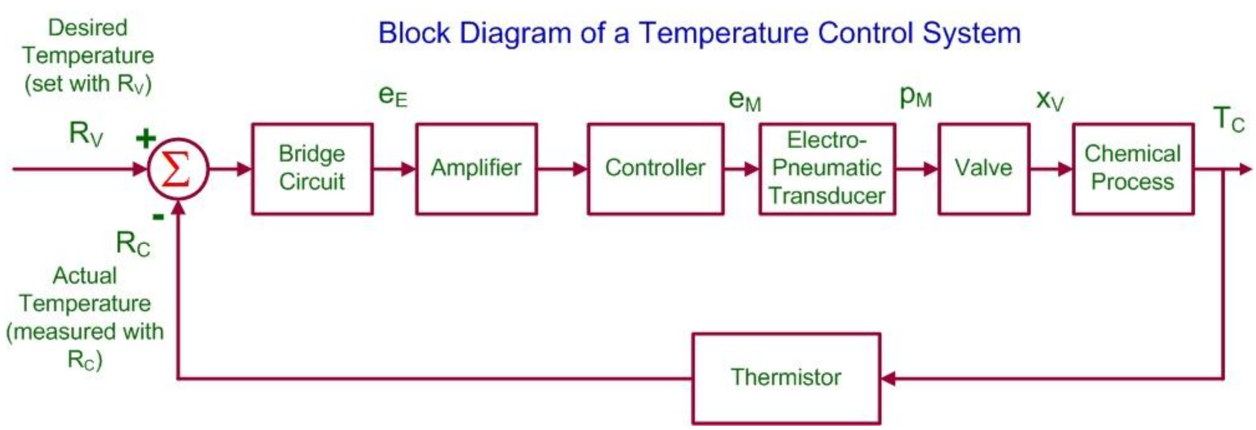
How does this device work? Let's use in addition to the schematic diagram, a block diagram to help explain its operation. A block diagram of a system is a pictorial representation of the functions performed by each component and of the flow of signals. It depicts the interrelationships that exist among the various components. Inside each block is a description in words or equations of what that component does. It is easy to form the overall block diagram for the entire system by merely connecting the blocks of the components according to the signal flow. It is then possible to evaluate the contribution of each component to the overall system performance. A block diagram contains information concerning dynamic behavior, but it does not include any information on the physical construction of the system.

In this device, the input, or command, voltage e_{in} is applied to the coil of wire, causing a current i_c to flow in the wire. Since this current lies in the magnetic field of the permanent magnet, the coil feels a magnetic force f_m. The coil is rigidly attached to the vertical rod which is constrained to move vertically by the two leaf springs which are cantilever beams. A cantilever beam is a beam fixed at one end but free to move at the other. For small motions, that free-end motion is approximately vertical. The cantilever beam acts mainly like a spring. This force causes the coil and vertical rod to move, bringing the flapper closer to the air nozzle and raising the output pressure p_o. The resulting coil and rod motion is opposed by the leaf-spring (the cantilever beam acting like a spring) force proportional to coil and rod displacement and the fluid damping, energy-dissipating, force (to reduce unwanted oscillations) proportional to the coil and rod velocity. The coil / rod mass, leaf springs, and the damper / float device comprise what is called a mass-spring-damper system. The pressure, acting over the flapper area A_p, causes a force f_p which opposes f_m. We have seen one electromechanical effect in this device, the motor effect, which says that the passage of current through the coil causes it to experience a magnetic force proportional to the current. There is another electromechanical effect present here, the generator effect. It says that the motion of the coil through the magnetic field causes a voltage proportional to velocity to be induced into the coil. This is called the back electromotive force (back emf).

For a steady (not time-varying) input voltage, the system will produce an output pressure such that the forces are balanced and equilibrium exists. Thus, we can conveniently control the pressure by changing the input voltage. Desirable performance characteristics of such a transducer include linearity (output pressure proportional to input voltage) and adequate speed of response. In addition to the one controlled input to the system, the input voltage e_{in}, there are possible undesired inputs that must also be considered. For example, the ambient temperature will affect the electric coil resistance, the permanent magnet strength, the leaf-spring stiffness, the damper-oil viscosity, the air density, and the dimensions of the mechanical parts. All these changes will affect the system output pressure p_o in some way, and the cumulative effects may not be negligible.

Now consider the temperature feedback-control system, the schematic and block diagram of which is shown. This is also a dynamic engineering system. A feedback-control system is one in which the actual system output is measured and compared to the desired system output and, based on this difference, an appropriate corrective action is taken. Feedback control is prevalent in engineered devices and systems.





This system uses the electro-pneumatic transducer as a component. The purpose of this system is to regulate the temperature T_C of fluid leaving a process vessel. This temperature is measured with a temperature-sensitive resistor (thermistor) and compared with a desired-temperature setting effected by manual adjustment of the electrical resistance R_V. If the two temperatures (and thus, resistances) are not equal, the bridge circuit produces an error voltage e_E, which is amplified and applied to an electronic controller. The controller output voltage e_M is applied to the electro-pneumatic transducer, whose output pressure p_M positions the steam-flow control valve. Manipulation of steam flow-rate through the heat exchanger allows control of process-fluid temperature T_C. Note that the detailed operation of the electro-pneumatic transducer is not of interest here; only its overall simplified input/output relation is required.

The designer of the temperature feedback-control dynamic system would consider the electro-pneumatic transducer as an off-the-shelf component with certain desirable operating characteristics and would not be concerned with its detailed operation. Of course, the engineer designing the electro-pneumatic transducer to meet some desired performance specifications is very much interested in its detailed operation, as it is those details that determine its overall performance.