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AUTOMATION

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Explanatory Notes

E=m·c²	Definition
	Interesting
i	Note
	Example
	Summary
+	Advantage
–	Disadvantage

ANNOTATION

This module provides an introduction to industrial automation and automation in general. It describes theory for logical systems, sensors, actuators, types of control systems like PLC, PAC etc., main control principles and SCADA systems.

OBJECTIVES

Theory of logical systems and control.

Sensors – with concern on measurement temperature, flow, pressure, height and position.

Actuators – pneumatic, hydraulic, electric motors, drives

PLC, PAC PCS systems, industrial control – description and differences.

Regulation – approaches and PID description.

SCADA systems – purposes and descriptions

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Index

1 Theoretical Background

Control systems could be divided into three groups:

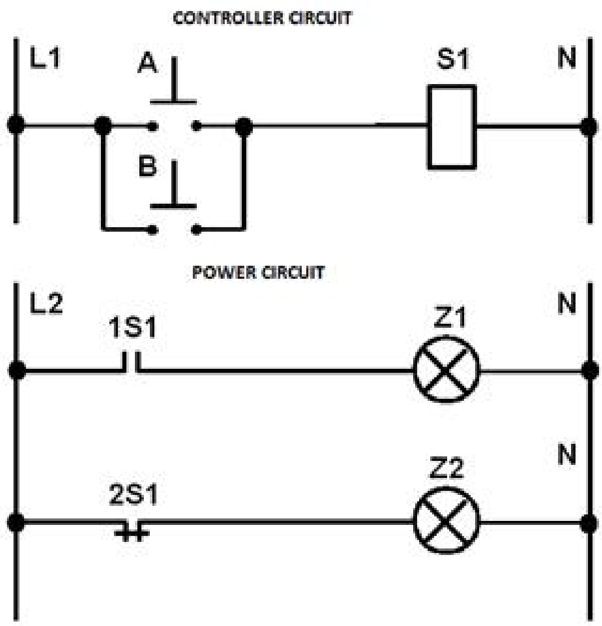
- Logical systems
- Numerical systems
- Hybrid systems

Logical systems

Logical systems are systems which communicate with neighborhood due to binary signals (yes, no or 1, 0 etc.) Information by these systems are made by Boolean algebra rules, and so called Boolean or binary systems. Binary system can be implemented by contact or contactless switching.

Binary systems can be implemented in different technologies, which are applied to logic functors. E.g. in control schemes, using transistors and even housing: Fixed logic, FPGA, program uC, DSP, PC, Control schemes.

Electrical control schemes are drawings in which is shown the control and power circuit. Elements of the main circuit are controlled by switches, power contacts of contactors or relays. The control circuit is composed of controls such as buttons, switches, timers and limit switches, coils, relays or contactors. Both elements can be replaced by weak-and power electronics.



Example for control scheme

The figure is drawn diagram of the control and power circuits with simple functions. Press A control voltage is applied to the contactor coil S1 is closed. Its normally open contact connected to the 1S1 voltage appliance (lamp) Z1, while NC 2S1 Z2 appliance disconnected from the power supply. The function of the circuit is such that pressing the A button will light lamp bulb goes Z1 and Z2. Release the button and the result will be the opposite.

Independent variable, and realized two logical functions, equivalence and negation.

Numerical systems

Numerical systems are the systems, which works with arithmetical operations and are under algebraical rules. It’s mostly basic algebraical operations addition, subtraction, multiplication and division, and possibly using much more complex operations and functions. Numerical system is executed by microprocessor.

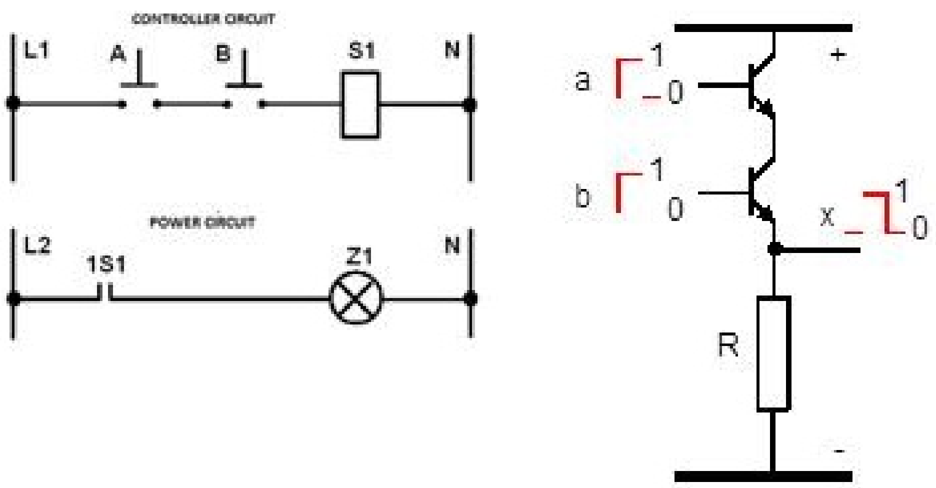
Hybrid systems

Hybrid systems are combination of logical and numerical (continuous) systems, and have special behaviour. Hybrid systems are executed by microprocessor too.

1.1 Implementation of Basic Logic Functions of Different Technologies

Logical conjunction – AND

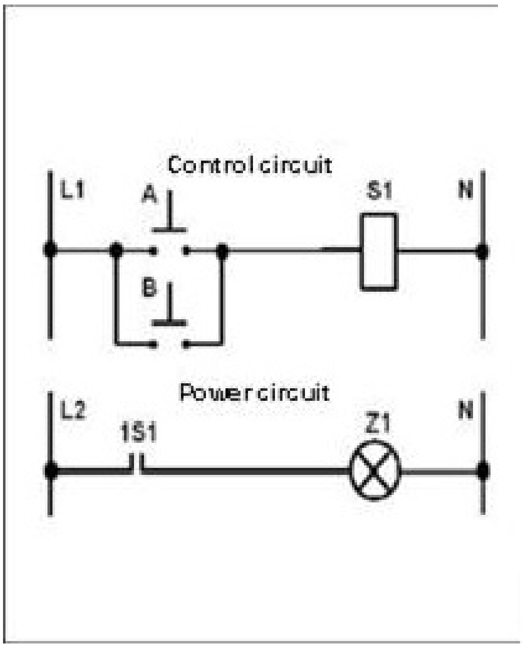
In the following examples, it is possible to study the technical implementation of the conjunction of two independent variables. The dependent variable takes value true only if at the same time both the independent variables are true. The control circuit is the solution to serial connection buttons. Implementation of transistors is solved using serial connection of transistors.

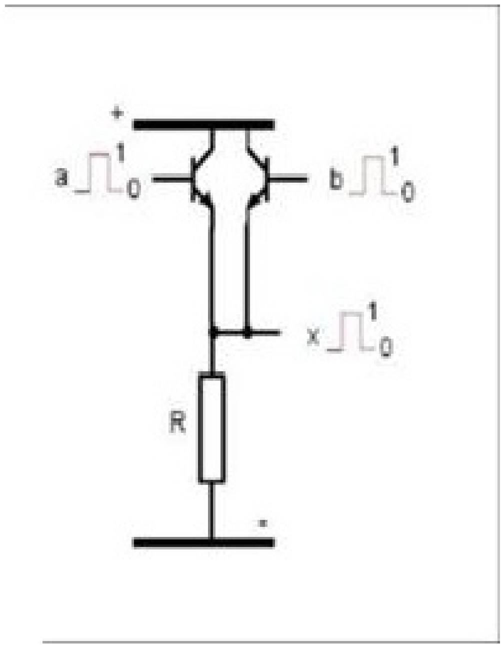


Logical conjunction function – AND

Logical disjunction – OR

In the following examples, it is possible to study the technical implementation of the disjunction of two independent variables. The dependent variable takes a value of true if at least one independent variable is true. The control circuit is connected in parallel solution keys. Implementation using transistors is also dealt with parallel connection of transistors.

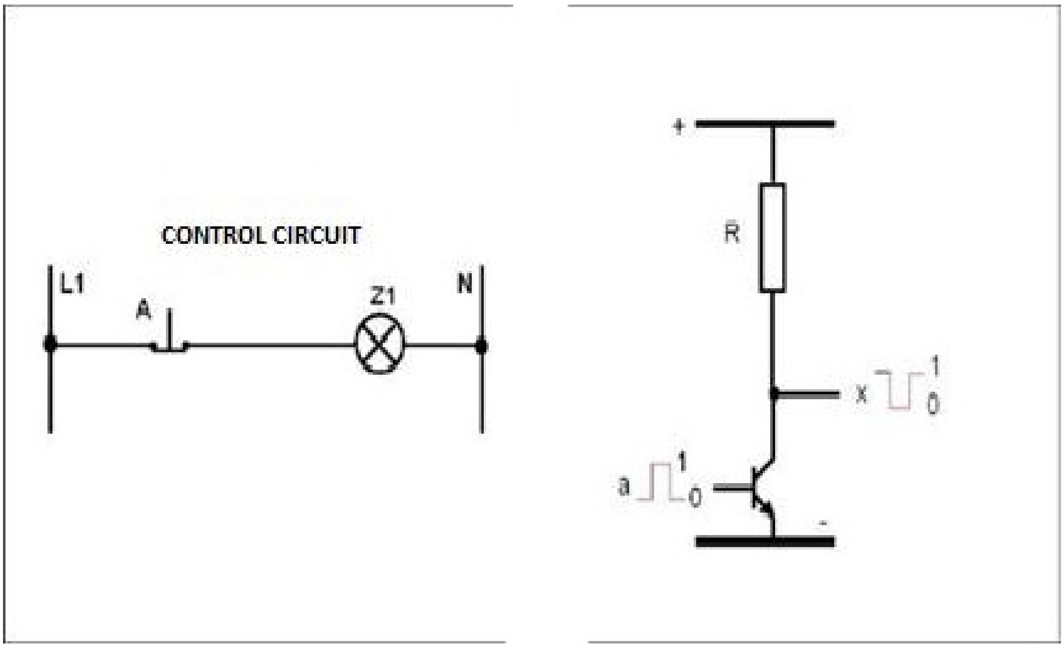




Logical disjunction function - OR

Logical negation – NOT

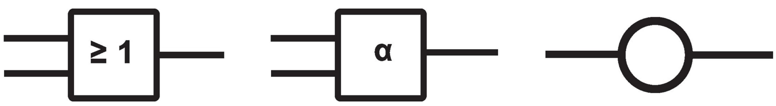
In the following examples, it is possible to study the technical implementation of the negation of one independent variable. The dependent variable takes a value of true if the independent variable is false. The control circuit is the solution involved opening contacts button. Implementation is solved using a shorting transistor voltage transistor.



Logical negation function – NOT

Schematic symbols for logic circuits

Given that the logical operations can be implemented using different technologies are generated logic diagrams. In logic circuit diagrams schematic symbols are used. Figure 3.2 Circuit symbol to represent logical sum, which has two inputs (left) and one output. Figure 3.3 is the schematic symbol for the logical product, which has two inputs and one output. Wheel in Figure 3.4 indicates negation. The diagrams are not drawn separately, but always in input or output tag for the product or sum.



Pictograms for logical operations

Note: In some, particularly older schemes may be signs of another shape, not a square or a rectangle. Mark for negation is the same.

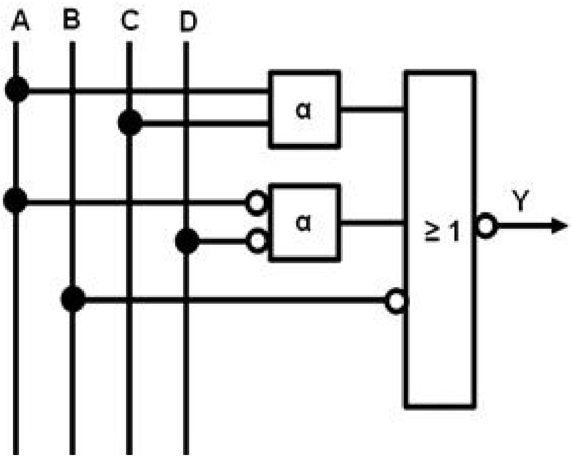


Diagram of the circuit

Draw the logic diagram of the circuit, which is expressed by the relation: $Y = \overline{A \times C + \overline{A} \times \overline{D} + B}$

Editing logical expressions

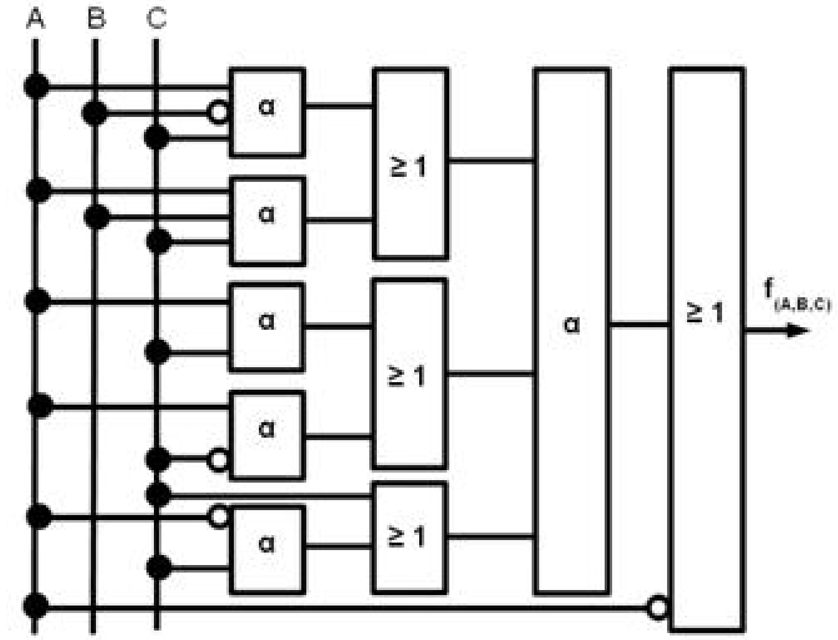
It is clear that each logic operation is represented by a single block in the logical schema that represents the relevant technology. The more logical blocks, the more components and the greater the probability of the failure of the control system. Reducing the number of used logic blocks is achieved by modifying and simplifying the logic functions. The simplification is performed on the basis of Boolean algebra rules, as stated in paragraph. Found source of reference. For clarity, the following example:

Example 1.1.5:

The function f (A, B, C), three logical variables is given by the following relation:

$$f_{(A,B,C)} = \left(A \times \overline{B} \times C + A \times B \times C\right) \times \left(A \times C + A \times \overline{C}\right) \times \left(\overline{C} + C\,\overline{A}\right) + \overline{A}$$

For its implementation need 14 logic blocks and the logic diagram is depicted in the following figure:

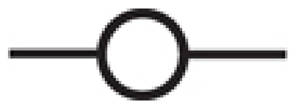


Logic Diagram

After making changes mathematical logic function is the following result:

$$f_{(A,B,C)} = A \times C \times \left(\overline{B} + B\right) \times A \times \left(C + \overline{C}\right) \times \left(\overline{C} + \overline{A}\right) + \overline{A} = A \times C \times \left(\overline{C} + \overline{A}\right) + \overline{A} = \overline{A}$$

This means that the result does not depend on the values of the logical variables B and C. The result is only negation of A. Implementation in the logical diagram in the following figure:



Negation

Comparing the two schemes, it is clear that there is a significant saving of logic blocks and thus reduces the probability of failure control system.

2 Sensors

Technical elements that provide conversion of a physical quantity to an informatively well-processed quantity, (e.g. pressure to electric current). Sensors are based on different physical principles and provide unification to signals, which could be processed in control systems. Nowadays commonly used term is the intelligent sensors - integrate all the measuring chain functions into one element with a digital output, e.g. using the data interface (RS-232C, RS-485, EIB etc.). Sensors typically consist of:

- Sensor transmitter;
- Measuring circuit and amplifier;
- Signal processing circuits;
- Analogue to digital converter;
- Communication circuit.

Sensors could be also divided by criteria:

- Signal transformation – active, passive
- Measured quantity – e.g. pressure, flow rate, temperature etc.
- Manufacture technology – e.g. mechanical, electrochemical, etc.
- Physical principles – resistance, conductivity, thermoelectric phenomena etc.
- Interaction with the measuring environment – contact, contactless

2.1 Temperature Sensors

One of the most common inputs for automatic signal processing in technologies. Temperature is also one of the most important quantities to affect conditions and processes in nature, generally.

Resistance Temperature Sensors

Metal resistance temperature sensors – the most frequently used methods of measuring in practice. The principle of metal resistance thermometers is the dependence of clear metal upon temperature, the resistance of metal raises almost proportionally to the absolute temperature.

Sensor Material	Measuring Range (°C)	Temperature Coefficient of Resistance
Pt	–200 to +850	3.85 to 3.93
Ni	–60 to +180	6.17 to 6.70
Cu	–200 to +200	4.26 to 4.33

Semiconductor Polycrystalline Sensors (NTC)

Sensors made of amorphous polycrystalline semiconductors, the so-called thermistors (thermally sensitive resistor). The dependence of electric resistance of material on temperature is used. The principle of semiconductor conductance is different, which relates to different behaviour and with different properties of these sensors. The resistance of semiconductor material weakens with growing temperature

Thermistors **NTC** (*Negative Temperature Coefficient*) have a negative temperature resistance rate, which corresponds with the mentioned description. For the use where sensor speed is important, miniature, so-called bead thermistors are interesting, as their little heat capacity shortens the time invariable of the sensor to seconds. The usual temperature scopes are -50 to 150 °C, and special ceramic thermistors for extreme temperatures (from i.e. 4 K to 1 000 °C) are also manufactured.

Semiconductor Monocrystalline Sensors

These are made of silicon, germanium or indium.

Thermoelectric Thermometers

For temperature measurement they use thermojunctions which consist of two conductors of two different metal materials A and B, and which are conductively connected at both ends. At the temperature difference tm and ts of the second connection, thermoelectric tension and thermoelectric current generate.

Contactless Temperature Measurement

Works on the basis of a physical effect, where matter owing to thermal motion of elementary parts emits energy in the form of electromagnetic radiation in the part of the spectrum, which is called infrared, but also in the visible part of the luminous spectrum.

Contactless Temperature Measurement – Bolometer

Principle of a bolometer is that the electric resistance of the bolometer changes in dependence on its temperature which depends on the quantity of the incident infrared radiation. The change of the bolometer's resistance therefore characterises the amount of the incident infrared radiation. Thermal insulation from the surroundings is essential. Microbolometer integrates more resistance facets on one face and in conclusion it enables a 2D thermoimage display of the radiating objects in front of the detector. Devices of many categories are nowadays available ranging from a simple one-point manual infra-thermometer up to thermocameras using the above mentioned principles with highly sophisticated digital control.

The main benefit is the contactless measuring. Other benefits are numerous, for example the possibility of measuring moving objects or possibility of 2D depiction, i.e. thermovision.

2.2 Pressure Measuring Sensors

Also one of the most often executed measurements. Various physical principles are used with pressure measurements that are usually distinguished according to the type of pressure conversion to the output signal of the sensor. Pressure gauges in industrial practice can be divided according to principle into hydrostatic, deformational, piston, and electric pressure gauges.

Pressure Measuring Sensors

Devices for pressure and underpressure measurement are commonly called manometers – underpressure gauges (vacuometers) and devices for the measurement of pressure differences are called differential pressure gauges, devices for measuring barometric pressure are called barometers and devices used for measuring absolute pressure are called absolute pressure gauges. Another term is the so-called pressure sensor – a pressure gauge, which works as an automation element. The pressure converter has a very similar significance as pressure sensor, it is an electronic device designed to measure pressure, which is able to convert the measured pressure data through electric signals to other devices. When the function of the pressure converter or sensor is controlled by a microprocessor, the converter or sensor of pressure are called intelligent.

<table>
<tr><th>Pressure sensors</th><th>Type of pressure sensor</th><th>Possible use</th></tr>
<tr><td rowspan="4">Hydrostatic pressure gauges</td><td>U-pipe</td><td rowspan="4">In laboratories, in metrological laboratories, accurate barometers</td></tr>
<tr><td>Container</td></tr>
<tr><td>Micromanometer with a inclinable arm</td></tr>
<tr><td>Compression vacuometers</td></tr>
<tr><td>Force pressure gauges</td><td>Bell, Piston</td><td>Standard pressure gauges (pressure gauge for measuring tire inflation)</td></tr>
<tr><td rowspan="2">Deformation pressure gauges</td><td>Bourdon-tube, membrane, Corrugated</td><td>Most common directly displaying practical pressure gauges.</td></tr>
<tr><td>Box-type</td><td>Aneroid for measuring barometric pressure</td></tr>
<tr><td rowspan="4">Pressure sensor with electric output (electromechanic pressure gauges)</td><td>Potentiometer, Induction, Optical</td><td>As a supplement of deformation manometers</td></tr>
<tr><td>Capacity, Tensometric</td><td>Most used sensors in modern converters of pressure, practical and laboratorial devices</td></tr>
<tr><td>Resonating</td><td>Belongs to the most accurate pressure gauges, practical and laboratorial devices</td></tr>
<tr><td>Piezoelectric</td><td>Measuring fast overpressure processes and pulsations</td></tr>
<tr><td rowspan="3">Electric pressure gauges for extreme pressures</td><td>Resistance</td><td>Measuring great overpressures</td></tr>
<tr><td>Heat conductive</td><td>Measuring great vacuum</td></tr>
<tr><td>Ionizing</td><td>Measuring extreme vacuum</td></tr>
</table>

2.3 Flow Sensors

There are many devices for flow measurement and the measuring of flow amount of fluids (liquids and gases). Gauges are equipped with advanced processing of measured data and the output data indicates the flow amount. Flow can be also evaluated by measuring the local or mediate speed of the medium flowing through the known cross-section, usually at given operating conditions (p, T). The current trend of flow meters is focused on the direct measurement of mass flow, i.e. measuring independent on temperature, pressure and viscosity of the fluid measured. The result of flow measurement may be presented either as a mass flow rate QM (e.g. $kg \cdot s^{-1}$), or volume QV (e.g. $m^3 \cdot s^{-1}$) where m is the mass, and V is the volume in the measured medium. Modern devices are equipped with electronic circuit for automated correction of temperature and pressure during the measurement. The trend of flow meter development is focused on the direct measurement of mass flow, i.e. independent on temperature, pressure and viscosity of the fluid measured.

Volume Gauge

So-called absolute methods- used for accurate measurement and verification of other types of flow meters. The measurement alone is based on the principle of admeasuring the volume of the fluid in the measured spaces.

Membrane Gas Meter

It is used to measure the volume of gas; it is equipped with two chambers divided by membranes. It is for example used to measure the quantity of heating gases.

Drum Gas Meter

In a horizontal cylindrical container partly filled with liquid the measuring drum is fulcrumed which is equipped with slots for the inlet and outlet of the gas and divided into four measuring spaces by radial bulkheads. It is used for precise laboratory and verification measurements.

Piston Flow Meter

It belongs among the most accurate. Measuring spaces bounded by a piston and the body of the gauge are alternately filled with specific fluid and emptied. Piston gauges are suitable for the measurement of even very viscous fluids.

Speed Gauges

Determine flow based on measured values of local or average speed and knowledge of the flow profile and the clear area.

Speed Sensors

Using the dependence of dynamic pressure of the flowing medium on the speed of flow.

Pitot Tube

It is tube curved at right angle to the plane of its opening situated vertically to the direction of the flow. At the sensor's issue the flow drops in practice to zero and all the kinetic energy transforms into potential energy. The sensor scans the total pressure p_c, which is the total of static pressure p_s and a dynamic pressure p_d.

Static Pitot Tube

Measures p_c and p_s in one place. The mentioned sensors are used for short-term measurements and measurements of velocity profiles. The lower measured speed limit for gases is about 6 m/s and for water 0.2 m/s.

Section Gauges

Within the pipeline a throttle organ is located, narrowing the flow cross-section. The difference of static pressures in the fluid before and after the narrowing, scanned with the differential pressure meter, depends on the value of the flow rate. The most used throttle organs are a centric circular shutter, jet and a Venturi tube. Among the special throttle organs there are square and rectangular shutters and a square Venturi tube, used with rectangular or square cross-section pipeline.

Rotameters

It forms a group of so-called cross-cut gauges, whose flow area changes with the flow at approximately constant pressure gradient in the narrowed cross-section. The main functional parts are a vertically placed slightly cone-shaped tube, extending up (the cone angle is less than 2°).

Turbine and Paddle Wheel Flow Meters

The speed of rotation of the rotor, paddle wheel or bolt is proportional to the mean flow velocity.

Slip is continually proportionate with the strain torque of the rotation part, i.e. the rotor, and it is influenced by the immediate value of the flow. According to the direction of flow, axial and radial flow meters are distinguished.

The turbine flow meter is a representative of axial flow meters; the rotor is made from blades attached to the hub stored in the bearings. Gauges are manufactured in a wide range of measuring ranges up to hundreds of m^3/hour. Turbine flow meters are suitable for liquids and for gases. For pulse scanning of rotation speed different sensors are used from mechanical to contactless ones. Pulses are further amplified and shaped.

The rotation frequency of the turbine is proportional to the immediate flow. Contactless sensors are advantageous in terms of digital signal processing. To determine the immediate flow, the constant period is added to pulses and the A/D converter is not necessary. The relative measurement error can be <0.5%, pressure to 30 MPa and temperature of –200 ... +200 °C.

Inductive Flow Meters

They are based on the use of Faraday's law of electromagnetic induction during the movement of a conductor in a magnetic field. With the electromagnetic inductive flow sensor, the moving conductor is represented by an electrically conductive liquid. A permanent magnet or electromagnet creates a magnetic field within the pipeline and liquid.

The section of the pipeline between the poles of the magnet mustn't be made of a ferromagnetic or conducting material. The internal diameter of the flow meter's measuring tube incorporates two electrodes for sensing induced voltage. The alignment of the electrodes is vertical to the direction of the magnetic lines of force. An inductive flow meter consists of a non-magnetic cylindrical measuring tube with two appropriately placed scanner electrodes.

Ultrasonic Flow Meters

These flow meters can be divided into two basic groups according to either the use of the Doppler Effect, or the measurement of the ultrasound signal transit time.

Doppler Effect Ultrasonic Flow Meters

The principle of an ultrasonic flow meter measuring signal transit time.

It can be used if the flowing medium contains sound reflective particles, for example solid particles or gas bubbles. The flow meter consists of an ultrasound transmitter and receiver, installed on one side of the pipeline. Ultrasonic signal of a known frequency around 1.2 MHz is transmitted to the flowing liquid, where it is reflected back from a moving particle or bubble, and when the receiver senses the reflected signal the frequency of the received signal is evaluated. The difference between the two frequencies is commensurable to the speed of the flowing media.

Ultrasonic methods can be used for measuring small and large flows of clean, contaminated, and aggressive liquids, for the measurement of pulsating flows and the measurement of sludge and melts flow at high temperatures.

Heat Flow Meters

Their principle is processing energy balance during heat sharing from electrically heated heating elements of the flowing fluid, during which the distribution of temperature changes. Changes in temperature are proportional to the mass of the flowing liquid. The following basic types exist.

Mass Thermoanemometer

It is a thermal mass flow meter; whose temperature sensors intervene directly in the flowing fluid – the cooling effect of the forced convection on the heated sensor is evaluated. Two resistance thermometers are located within the pipeline.

2.4 Heights and Positions

Measuring Heights and Positions

This is a typical measuring automation task specific particularly by the type of concrete measurement, e.g. liquid surface, bulk materials. Height measurement is usually a primary indication of quantity calculation. It is possible to calculate quantity using the data recorded while measuring height, while it of course depends on the shape of the container, for example the reservoirs in which a specific surface level is measured. If the measurements are carried out in containers of an unalterable cross-section and height, the evaluation is very easy.

Ultrasound Height Measuring

Altimeters (mostly in the form of level gauges) based on the principle of ultrasound use two methods. In one case, the transit time of the ultrasonic wave from the transmitter via the reflection of the surface back to the receiver is measured and distance is calculated from the measured time and the known speed of ultrasound in a known environment. This method is used for continuous measuring of surface level position. The second method evaluates the attenuation of ultrasonic waves in dependence on the environment's composition, which the ultrasound passes through. They are apt for continuous contactless measuring of surface level positions in open and closed tanks with liquid or bulk materials. They can be used with polluted slush and pasty matters and, in certain circumstances, to detect the level of foam. The benefits are the absence of moving parts, noncontact continuous measurement, the possibility installation on the outside of the tank without breaking its seal, the compact design of sensors, resolution up to 1 mm, and high accuracy of measurement. A disadvantage can be in the possibility signal affection by the presence of heavy fume and dust and the disruptive action of the turbulent surface level and the presence of foam.

Radar and Laser Measurement of Height and Distance

Radar level sensors work analogically with ultrasonic level gauges, however, when using electromagnetic waves, which spread through the medium at the speed of light. Microwave radiation is defined as the frequency of waves larger than about 2 GHz. Radar level gauges use two methods of measurement, the time (pulse) method and the frequency method (with chirp continuous signal).

Radar level gauges operate without moving mechanical parts, and show great accuracy (± 1 mm) and reliability even at very difficult operating conditions (high temperature, pressure, aggressive environment). The laser sensor for distance measuring transmits million short pulses of laser light per second and records the time it takes them to reach their goal and back to the sensor. Generally, the large range of the sensor allows it to measure the distance of small elements or objects even when the sensor is installed within a long distance from the dangerous area of the manufacturing process. The clear and well visible light emitted by the laser beam expedites the sensor's activation.

3 Actuators

Actuators named instruments which are operated directly by supervisory systems outgoings. Follow we'll try to describe small set of used actuators but we'll try to cover main ones.

Electric Motors

One of the most used kind in automation (we have in mind mostly controlled) are electrical motors – drives. We can divide them into linear and rotating. Characteristic for these equipment today is possibility of higher type communication, e.g. by analog output, by serial link (RS-232C, RS-485), which can be used for control rotation speed, position etc.

Direct Current Motors

These motors consist of stator (fixed part) with main poles with excitation coil and helping coil, placed between main poles for improving commutating properties. Moving part - rotor rotating in magnetic field, which consists of metal plates.

Biggest current flows into rotor coils in quiet = motor make big starting torque. On the other hand, in speedy rotating rotor there is inducting tension reductive current flowing into rotor coils and torque with increasing revolutions is lowering. Motor with these torque speed-torque characteristic easily overcomes varying load.

Synchronous Motors

Main characteristic of these motors is equality of rotor speed with magnetical stator field. Alternate current in stator winding (1 or 3 phases) generates stator rotating magnetic field. Rotor can be made from permanent magnet with alternative designed poles around circumstance or has winding powered from DC power source (excitor) and making electromagnet. Excited synchronous motor after direct connection to AC link isn't rotating by itself. Three-phase AC in stator makes rotating magnetic field which is rotating by rotating speed given by frequency of power source and number of poles in motor. Rotor, which is stopped, is powered by direct current and it excites stationary magnetic field. There is an action of force stator and rotor field by interaction these two fields. Direction of this force is changed with stator rotation speed.

Stepper motors with respect to growth of digital control systems and working with digital information it's enlarging of usage so-called stepper motors, where steering angle of shaft is given by number of impulses on control winding. Characteristic is discontinuous shaft movement done by angle jumps = steps, which are done by response to one control impulse.

Asynchronous Motors

Principle of function is based on mutual electromagnetic influence of rotated magnetic field of rotors and stators and currents generated in rotors winding by this magnetic field.

Asynchronous motor is based on induction tensions and currents in rotor and this is the reason, why we call it also inductive motor. Rotated magnetic field is in asynchronous motor generated in stator (stable non-rotated part) winding, which is made as three-phase, where winding is turned 120° in space.

Awe recognize: Single-phase asynchronous motors, Two-phase asynchronous motors, Three-phase asynchronous motors

These types are used mostly.

Pneumatic Actuators

By design are pneumatic drives dividing into piston and membrane types. Membrane drives are mostly used for linear control in valve technique. Rotating types are designed for control regulation rotation armatures or clack valves.

Control force of pneumatic drives is between 0.5 kN and 90 kN. These drives are only single acting function, which means that pressure of control medium forcing contra spring. Described design is able to apply these action elements as emergency drives too, because in case of losing press of control media it's able to shift closing part by function to set position. According to springs design in driver hat function for pneumatic drives is:

- Direct function (NO – normal open) – drives type without press for control media open;
- Indirect function (NC – normal closed) – drives type without press control media close.

3.1 Hydraulic Actuators

Hydraulic actuators are suited especially for high-force applications. Produced force is 25 times greater than pneumatic cylinders of equal size. Also have high horsepower-to-weight ratio by 1 to 2 hp/lb greater than a pneumatic motor. What is also important is that can hold force and torque constant without the pump supplying more fluid or pressure due to the incompressibility of fluids. These type of actuators can have their press sources (pumps and motors) located a considerable distance away with minimal loss of power. But exists some disadvantages too like leaking fluid. Like pneumatic actuators, loss of fluid leads to less efficiency. Requires many companion parts, including a fluid reservoir, motors, pumps, release valves, and heat exchangers, along with noise-reduction equipment.

Frequency Converters

Used for smooth control of asynchronous motors with squirrel cage - means rotation speed, torque, starting and after running. Control is implementing by changed power supply frequency combined with control voltage per semiconductor frequency converter – it´s compound from indirect voltage frequency converter (rectifier, DC link, transistor inverter). DC link is mostly noncontrolled - diode. In DC link is filtration condenser for current filtering rectified voltage and suppressor for suppressing current shocks when uncharged condenser is connected and for improving network current – restriction harmonic and improve efficiency. From DC link is powered transistor inverter, which by pulse-width modulation shaped sinus output tension and control its effective value. Control of rotation speed is made by frequency changing optimally according to voltage motor. Frequency range is from 0 to nominal frequency supply network or to the higher frequencies. Frequency changes have program adjustable curve incl. current limits what can be used for control starting and after-running motor. With use frequency converter can be realized braking in modes: braking DC, resistor braking, regenerative braking.

Softstarters

Is also equipment for smooth starting asynchronous motors – starting with limits with restriction current and moment shocks, what is achieved by control voltage at motor clamps with unchanged network frequency by semiconductor changer of AC. They are used for motors with power from kilowatts to megawatts. Softstarters are able for one phase motors too. Softstarter for three phases motor is compound from three twins tyristors phase controlled and connected in antiparallel for power input. For Y-connected motors we can connect softstarters in triangle, so that softstarted will control only current in winding and in comparison for control phase current can be less dimensioned for current – it is used in particular for bigger powers. It is possible to use so-called bypass which provides after start by clamper overbridge connection and softstarter can be used for starting other motors. Softstarter has no possibility to control rotation speed of motor what is compensated by design control and power function and lower price. It is used especially for starting fans, pumps, compressors and there where is big inertial mass starting e.g. in conveyors, centrifuges etc. Softstarter is not suitable for drive with big starting torque.

4 PLC, PAC, PCS

These kind of control systems are probably the most widely used types. Older German resources use the abbreviation **SPS** (*Speicherprogrammierbare Steuerung*). Main features of the programmable automate comprise the fact that they are programmed by a user, but user-friendly. Programming in graphical languages resembles drawing of diagrams (contact or logical diagrams, block diagrams, state diagrams). They are easy to learn, so they may be used by machine designers or designers of automated systems when programming basic tasks. Programming languages for **PLC** are standardized by an international norm IEC/EN 61131-3. It defines 4 types of programming languages. The Instruction List language (**IL**) is a text language which resembles the assembler language – respective commands are mnemonic abbreviations for respective instructions. A program written in the **IL** language is usually long and lacks transparency. The Structured Text language (**ST**) is a higher-level language. It somehow resembles the Pascal language. It is powerful and algorithm-oriented. Most advantage type of programming. The Ladder Diagram languages (**LD**) is a graphical language which looks like a line-diagram once used for connection of switchboards and relay systems. The **LD** language is suitable only for writing simple, logical programs (not complex!), which use only basic logical operations and which require intuitive approach. The graphical Function Block Diagram language (**FBD**) resembles logical diagram of a logical system with integrated circuits, or a more general block diagram. Similar languages of block diagrams are used as well. The program is very transparent, if it is not extremely complicated. If using libraries of specialized function blocks (standard or user libraries), the programming in **FBD** may be very efficient.

With respect to size and mechanical arrangement, we usually distinguish several types of PLCs.

Micro PLC

It is the lowest class of programmable automat with a typical range of 10 to 20 inputs and outputs.

Compact PLC

It is a mid-class device with a typical range of 20 to 80 inputs and outputs, sometimes even a little bit more.

Modular PLC

It is a high-class device – with respect to possible configurations (typical range of hundreds to thousands of inputs and outputs, various types and combinations, specialized peripheral modules, various types of central units and communication modules, industrial computers modules), and their computational power and possibilities of communication.

5 Other Control Systems

SoftPLC systems are usually SW implemented at industrial computers that use usually programming according to the standard IEC/EN 61131-3 (described above). The main advantages include the operating system and a simple way to activate standard software products, handling of standard peripherals of the computer, use of archive and communication functions, Ethernet interface, Internet communication and a significant computational power.

The risk of instability of the operating system is usually solved by the use of a robust, real-time operating system, or an extension module is attached to the standard computer which implements the functions of the programmable automaton (**PLC** module). There is a variety of methods to implement the SoftPLC systems. There are still other devices that may be programmed in the style of **PLC**, such as frequency converters programmable according to the standard IEC/EN 61161-3. Similar features are typical for some intelligent terminal modules.

The name industrial computers usually contain a wide class of computer products. The most common category is represented by embedded systems – these are systems that are "embedded" into a switchboard, control system or other device. Industrial computers are sometimes called by the abbreviation **IPC** (*Industrial PC*). It is sometimes used in the same meaning as embedded systems, in some cases it distinguishes a special class of PCs, which are specially constructed for extreme durability and unfriendly condition of the industrial environment.

Often used devices are presented by embedded computers with operator panels, usually with a touchscreen. Their main function is to implement the operator interface (**HMI**). Standard computer equipment, memory, communication and quality colour graphics enable comfortable visualization, monitoring and documentation of the state of the controlled object; at the same time, they provide a user-friendly interface. Similar function may be implemented by a compact embedded computer without a screen. - used mainly for its computational functions in many cases, for data archiving, communication functions, standard operating system; it may be used as a tool to access standard peripherals or software products. It may be used for archiving of large files of data, as a communication adapter (for Ethernet), Internet access point, or to perform numerically extensive computational algorithms.

Modular embedded computers are used for demanding applications. Similarly, to programmable automat (**PLC**), they are very versatile and their configuration may be modified according to the requirement of the controlled object.

Industrial computers are approached by programmable automata. Standard equipment for **PLC**s of majority of the main **PLC** manufacturers includes computer modules (i.e. embedded industrial computers), or the central units of the PLCs are implemented as a computer (somewhere between **PLC** and SoftPLC).

It is difficult to tell on the first sight, whether the control system is implemented as a modular industrial computer, programmable automat (**PLC**) or a SoftPLC system. The main classification criteria include the programming method and available programming languages (for PLCs, they comply with the norm IEC/EN 61131-3).

5.1 DCS

Distributed Control Systems (**DCS**) are large process control systems **PCS** (*Process Control Systems* – also used as synonyms), which began to be used in the 60 years with the advent of the first control computers, which represented the numerical solution of the centralized control of large technological systems such as chemical processes, power plants, etc. They were built as suitable centralized solution.

Some **DCS** systems are specialized, some are, however applicable in more areas. Exceptions are control systems, where extremely high demands on safety and reliability of the control system. Highly secure and reliable systems are very expensive and therefore not deployed where it is not absolutely necessary. These systems are characterized by strict hierarchical construction with three levels of control that is bottom-up:

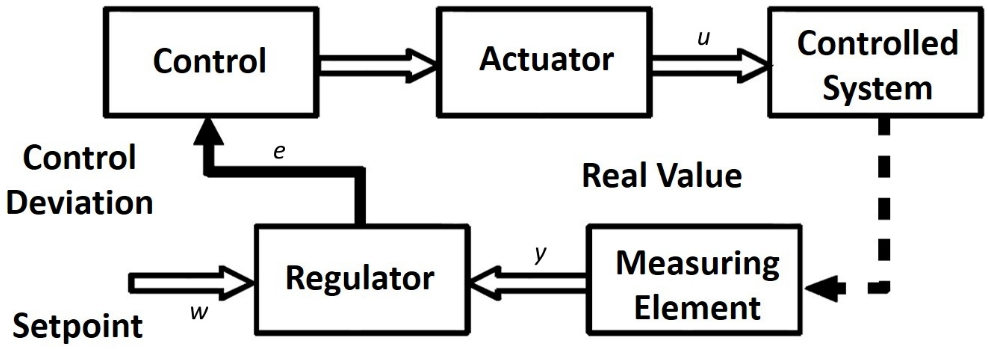
- Sensors level – sensors, actuators
- Level of the first control (technology control and regulation)
- Operator level
- Superior level

In any case, however, still represent a large **DCS** control system with only a high degree of reliability in areas where it is necessary to treat a large number of inputs and outputs of various types and where reliability and security is absolutely categorical requirement. Their advantage is also the compactness of the system.

6 Regulation

6.1 Regulation Control

Higher level for regulation is automatic control. Means that the system is controlled so that one or more physical variables are maintained at the prescribed parameters. An example of such a system may be gas furnace - controlled system, which performs preheating of material for reasons of a surface treatment (e.g. tempering). Material supplied inside the oven must be heated to a specified temperature and the temperature of the furnace, the regulatory circuits (control and regulation) to maintain a certain period of time (set point). Temperature must be measured and its size is controlled by control valve (actuator) supply of fuel gas. The system is controlled by one or more of the parameters measured. These may be any physical quantity: temperature, pressure, speed, power, voltage, etc. Measuring unit processes the measured value to the appropriate signal and passes it to the controller. Since this is a transfer of information from the system, this branch is called feedback. Also entering into the controller set point (value). It is the size of the regulated parameter. The difference between value and reference signals feedback control deviation occurs. Control deviation signal enters the control block, the size of which creates the appropriate control input to the actuator. Their activities affect the actuator system and its parameters.



Control regulation scheme

Control

Control is a process, using a feedback to reach desired aim (feedback control). The aim of the control is to reach and ensure desired value of controlled (output) value (e.g. room temperature, tank level) or the desired time behaviour (e.g. temperature behaviour according to weekly plan or a temperature in room according to specifications). The desired value must be assured not only after desired value change, but under disturbances, acting to a system, as well. The disturbances typically do have an unpredictable characteristic, e.g. thermal loss or increase in heated room (outdoor temperature change, window opening, draught, wall and room insolation, presence of persons or powered electric equipment).

Feedback

Principal schematic of feedback control system is shown on the Figure above. The input of the whole system is a desired value (*w*) and an output is the actual value (*y*). The subtraction element evaluates an error $e = w - y$, what is input to a controller. The controller processes the error and outputs a control variable, which acts via actuators to the controlled system (plant). The controller tries to minimize the error, for the actual value y to approach the desired w.

PID controllers

PID is the most used type of controller. The common property of ordinary **P**, **PI** and **PID** controllers is linearity. In case of proportional controller (**P**), the control variable is directly proportional to the error.

The control variable of proportional-integral controller (**PI**) is a sum of two components – the proportional one (which is, as well as in case of pure P controller, directly proportional to the error), and an integral one, which is proportional to accumulated value of the error, i.e. to its integral. Integral action is able to reach zero error in some cases, where it is impossible with pure proportional controller.

The output (control variable) of proportional-integral-derivative controller (**PID**) contains an additional derivative action. It has "anticipating" behaviour and brings faster response to sudden changes. Its disadvantage is that it amplifies high frequency noise, present in measurement, what may cause random, erratic operation of the system.

Until recently, **PID** controllers were implemented as analogue circuits, usually based on operational amplifiers. Controllers now are usually implemented in software. The software can run on a microcontroller, digital signal processor or a **PLC** in case of industrial application, or an ordinary personal computer.

Evaluates mathematical expression

$uk = p \cdot ek + i \cdot \Sigma ek + d \cdot \Delta ek$

Integral of the error is replaced by sequential sum of individual error value samples at each step ($\Sigma e_k = \Sigma e_{k-1} + e_k$). Derivation is replaced by a backward difference, i.e. the difference between actual and previous error sample $\Delta e_k = e_k - e_{k-1}$.

7 SCADA Systems

Translation for this term is Supervisory Control And Data Acquisition. That's mean, this is a software which enables supervision, control, archiving events of technological (or other of course) process. **SCADA** systems are often today used as middle level in control automation in huge companies linked for example to **SAP** systems or any systems of this category.

E=m·c²

SCADA is the software system operating with coded signals through communications channels to control a remote device. The control system is usually supplemented with a system obtaining information about the status of a remote device for its displaying, processing, and data recording.

E=m·c²

HMI (*Human Machine Interface*) is an imaging software that performs visualization of technological process. **HMI** provides the operator of a technological device detailed schemes up to specific sensors, provides information about technology management, provide information about trends and diagnostic data.

SCADA systems typically contains:

- *HMI* (*Human Machine Interface*)
- Remote terminals that converts signals of process sensor into digital data and enable connection of these sensors with the control centre
- Scripting language with ability to perform control of partial technologies or functionalities
- Connections possibility various networks – **WAN** (*World Area Network*), **LAN** (*Local Area Network*), Ethernet, SMS sending etc.
- Communication with HW of computers through layers like **HAL** to e.g. provide fastest displaying graphs, data etc. what in huge data amount is often very important.

All **SCADA** systems have two main functional parts 1. Development part/module and 2. Runtime modules.

On the market exits number of different versions of **SCADA** systems and we can name e.g.:

- Wonderware In Touch from company Schneider Electric
- WinCC from company Siemens
- RELIANCE from company Geovap
- CITECT from company Schneider Electric

- ControlWeb from company Moravské Přístroje – www.mii.cz
- RSView Studio from company Rockwell Automation

OPC (www.opcfoundation.org)

One of most important functionality is standardised interface (from **PLC**/**PAC**) for **SCADA** systems. It's wide spread and is base for standardisation because it makes independency *PLC* and **SCADA** systems because in previous times was normal than **PLC** supplier have to supply **SCADA** system too for compatibility reasons.