ViMeLa PROJECT

laboratory instruction

THE TEAM

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1. Introduction

1.1. Introduction

In the 21st century, higher education has moved from books and pens to the use of interactive technologies to facilitate students' understanding and impart knowledge. Nowadays, traditional education and teaching methods, although with significantly improved teaching techniques, cannot keep enough interest of the students that grew up with Internet, mobiles and tablets. Engineering and mechatronics students in particular are especially sensitive to these issues.

Modern information technology is rapidly being adopted in Mechatronics Engineering education as a tool for enriching practical experience of the students. The practical training is a vital part of Mechatronics Engineering education. However, the high cost required to implement laboratory experiments (for educational purposes) led to development of virtual facilities where physical systems can be virtually controlled via the Virtual Reality (VR) simulations.

Multimedia and VR technologies offer great potential for presenting theory and laboratory experiments in an empowering, interesting and relatively economical way.

The students are able to visualize abstract concepts, observe events in micro or macro scales, visit various environments and interact with events and devices that usually are unavailable due to place, time, or safety factor. VR laboratory simulations provide an interactive experience. Users can move freely around the environment, interact with objects, carry out tests, and make decisions and mistakes until they have mastered the subject.

1.2. Learning Mechatronics

Mechatronics is a synergy and an interaction of mechanical, electrical and computer systems as seen in Figure 1.1. Hence, it is an interactive combination of mechanical engineering, electronic control and computer technology, with the aim of achieving an ideal balance between mechanical structure and its overall control and performance. Subsystems of mechatronics are electromechanics, robotics and control.

The multidisciplinary concepts merged in the mechatronic engineering require an academic higher education that provides an appropriate balance between research and development capabilities, as well as skilled engineers trained for designing, manufacturing, implementation and service provision in their professional areas.

Currently, mechatronics classes are divided into two parts: the theoretical lectures and practical laboratory courses with experiments following "learning by doing" model.

1. Practical laboratory work, even with students' limited access to the machines, provides a deeper understanding of theoretical lessons. However, expensive equipment and limited time for training do not provide sufficient educational platforms. Moreover, due to the fact that each laboratory has to be supervised by technical staff and students have to be divided into small(er) groups, there is a limited time window for each type of exercise to be conducted.
2. In some cases, the students conduct exercises based on simulations and learn how mechatronic systems and devices operate in reality, despite the fact that it might seem abstract and unclear for students and does not fully reflect the physical phenomena of particular processes.

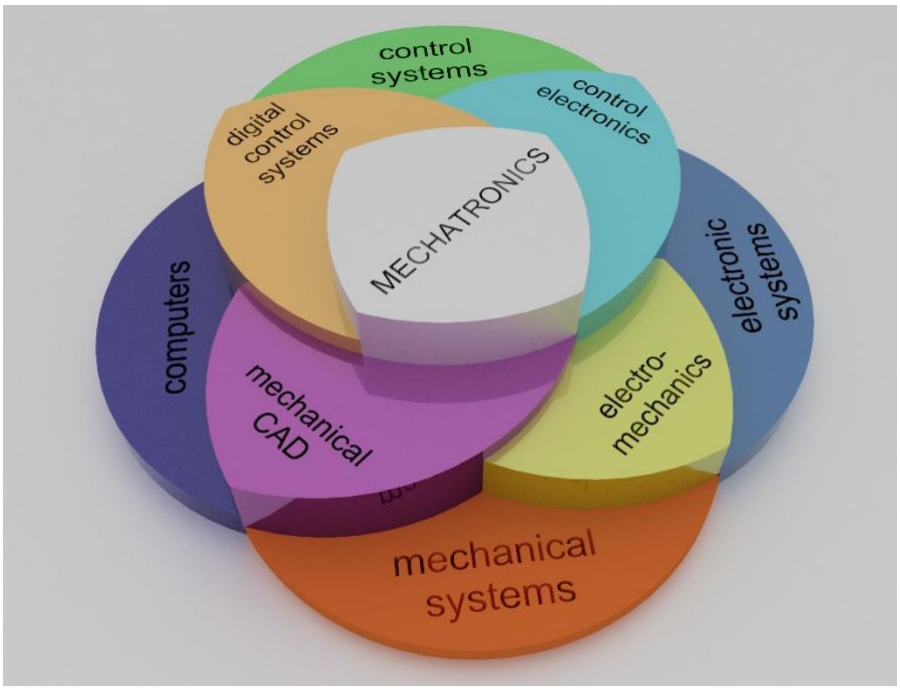


Figure 1.1. Structure and key elements of mechatronics

The described drawbacks of mechatronics study are greatly mitigated when classroom teaching is supported by VR technology and VR tools. These solutions provide an interactive experience in a virtual laboratory. The most significant outcome is that it facilitates learning of abstract concepts, as students can experience and visualize them in the virtual environment.

1.3. Virtual vs Real World

Virtual Reality, by its pure definition, can deliver experiences and interactions for students that are either impractical or unfeasible in the "Real World".

Virtual reality has existed in various forms as far back as the 1960s when the first digital flight simulators were developed. As technology advanced, "virtual reality" became the phrase to represent devices that create an immersive, interactive environment with visual realism. Desktop VR emerged during the early 2000s because personal computers became powerful enough to simulate and render 3D virtual worlds.

As a matter of fact, virtual reality simulation is a use of 3D objects and environments to create immersive and engaging learning experiences. The principle of virtual reality e-learning is to impart, practice and check the user's knowledge using interactive scenarios and

environments to reflect real-life situations. Using 3D technology to create what is referred to as real world environments presents unlimited options of generating any environment or situation. Thus, virtual reality simulation provides a truly interactive environment and experience. Students can move freely around the environment, interact with objects, carry out tests, and make decisions and mistakes until they have mastered the subject.

1.4. ViMeLa Project

The Virtual Mechatronic Laboratory - ViMeLa as an innovative tool for teaching and learning Mechatronics. The concept is based on a blended-learning method using theoretical classes and virtual reality – VR as an experimentation tool. Blended learning here is a hybrid method that combines digital media (through VR) with traditional classroom methods and is more effective in teaching mechatronics than face-to-face classes alone. The ability to easily change the virtual world opens new possibilities in testing and working with equipment, without the need to acquire expensive physical samples.

> "Tell me and I forget. Teach me and I remember.
> Involve me and I learn."
>
> (as per Benjamin Franklin)

The project comprises three scenarios:

1. Construction, operating principles and performance of electric motors;
2. Sorting line with pneumatic components;
3. Waste sorting line with belt.

The innovation of the proposed concept lies in developing an original and novel mechatronic learning system, based on VR technology. Digital interactive environment has been developed and create. It is a factory as seen in Figure 1.2, where the separate working spaces for the three scenarios are placed. The student can observe, enter and move around the area, with a possibility of dynamic changes to fit any given scenario.

Figure 1.2. Factory hall created in ViMeLa project using VR

"The only source of knowledge is experience"

(as per Albert Einstein)

2. Scenario 1 -Construction and Operating Principles of Electric Motors

2.1. Purpose of Scenario 1

The purpose of this part of the VR application is to familiarize the user with electric motors, their basic parts and construction, as well as the principles of operation. Therefore, 3D models of six authentic electrical machines are prepared in VR environment. The scenario consists of two parts. The first part of the exercise will enable the students to learn the main parts of the selected types of electrical machines and gain a skill for virtual assembling and disassembling of electrical machines in correlation with the proper selection of their main parts (i.e. stator core, rotor core, permanent magnets, windings, bearings, shafts, housings, etc.). The simulation module is designed to present the principles of the machines used in mechatronic systems. In the second part of the scenario the virtual model of a permanent magnet synchronous motor will enable the students to analyse the impact of supply conditions (i.e. values of voltage and frequency, pulse frequency) on the performance and its working characteristics.

2.1.1. Induction Motor (IM)

An induction machine is one in which alternating currents are supplied directly to stator windings and by transformer action (induction) to the rotor. The flow of power from stator to rotor is associated with a change of frequency, and the output is the mechanical power transmitted to the load connected to the motor shaft. The induction motor is the most widely used motor in industrial and commercial application of electric energy. Reasons for the popularity of induction motors include simplicity, reliability, and low cost, combined with reasonable overload capacity, minimal service requirements, and good efficiency. The rotor of an induction motor may be one of two types. In the wound-rotor motor, distributed windings are employed with terminals connected to insulated slip rings mounted on the motor shaft (Fig. 1.3). The second type is called the squirrel-cage rotor (Fig. 1.4), where the windings are simply conducting bars embedded in the rotor and short-circuited at each end by conducting end rings. The rotor terminals are thus inaccessible in a squirrel-cage construction, whereas for the wound-rotor construction the rotor terminals are made available through carbon brushes bearing on the slip rings. The stator of a three-phase induction motor carries three sets of windings that are displaced by 120 deg in space to constitute a three-phase winding set. The application of a three-phase voltage to the stator winding results in the appearance of a rotating magnetic field. It is clear that induced currents in the rotor (due to the rotating field) interact with the field to produce a torque that rotates the rotor in the direction of the rotating field.

The main parts of any IM are:

- The stator slotted magnetic core,
- The stator electric winding,
- The rotor slotted magnetic core,
- The rotor electric winding,
- The rotor shaft,
- The stator frame with bearings,
- The cooling system,
- Housing.

The induction machines may be classified in many ways. Here are some of them:

- With rotary or linear motion,
- Three phase supply, single-phase supply or multi-phase supply ,
- With wound or cage rotor.

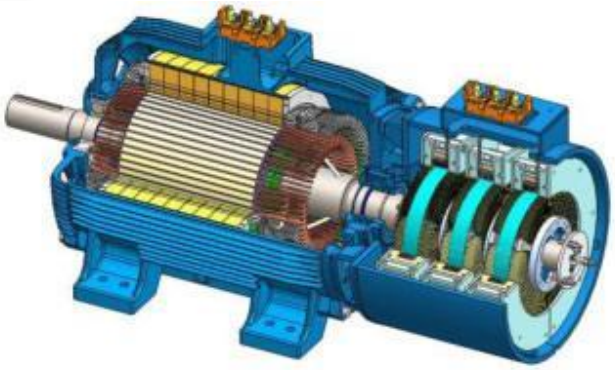


Figure 1.3. Induction motor with wound rotor

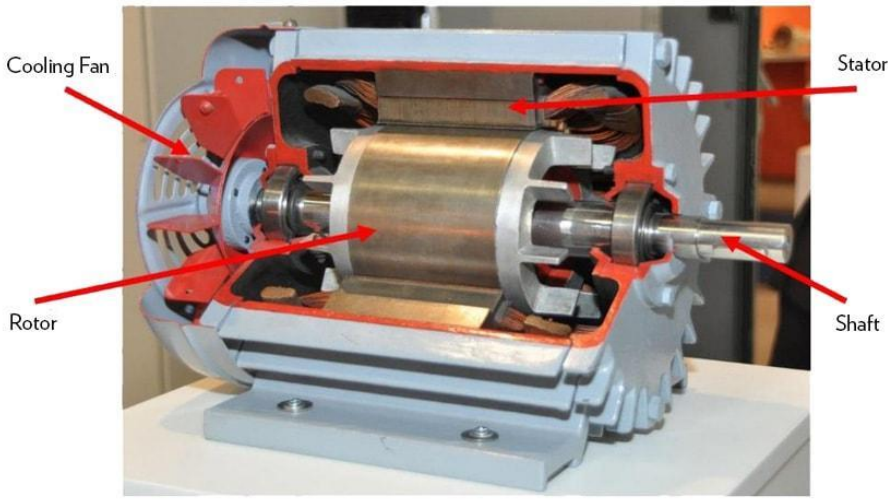


Figure 1.4. Induction motor with squirrel cage rotor

2.1.2. Synchronous Machines (SM)

A synchronous motor is a machine that transforms electric power into mechanical power or vice versa - it is a generator which transforms mechanical power into electric one. This means that the synchronous machines are reversible electrical machines. This also applies for all the other rotational electrical machines, such as induction machines and DC machines. The rotational speed of normal operation is exactly proportional to the frequency of the system to which it is connected. Unless stated otherwise, it is generally understood that a synchronous motor has field poles excited with direct current. In some new topologies the excitation winding is replaced with permanent magnets and then the machine becomes permanent magnet synchronous machine. In the last several years the manufacturers of electrical machines tend to produce permanent magnets synchronous generators that are mainly used as wind power generators.

The synchronous motor is built with one set of AC polyphase distributed windings, designated the armature, which is usually on the stator and is connected to the AC supply system. The configuration of the opposite member, usually the rotor, determines the type of synchronous motor. Motors with DC excited field windings on silent-pole or round rotors, rated 150 kW to 75 MW and larger are the dominant industrial type. In the brushless synchronous motor, the excitation (field current) is supplied through shaft-mounted rectifiers from an AC exciter. In the slip-ring synchronous motor, the excitation is supplied from a shaft-mounted exciter or a separate DC power supply. Synchronous-induction motors rated below 4 kW, usually supplied from adjustable-speed drive inverters, are designed with a different reluctance across the air gap in the direct and quadrature axis to develop reluctance torque and are named reluctance motors. The motors have no excitation source for synchronous operation. Synchronous motors employing a permanent-magnetic field excitation and driven by a transistor inverter from a DC source are termed brushless dc motors and if they are supplied by a three-phase supply they are termed as permanent magnet synchronous motors.

This section introduces the design evaluation of permanent magnet motors and reluctance motor, since these types of machines are included in the assembling part of Scenario 1. It is organized in the following manner. The three basic geometrical arrangements of permanent magnets (Fig. 1.5), for permanent magnet machines with conventional stators are:

1. Surface-mounted magnets.
2. Interior permanent magnets.
3. Buried permanent magnets.

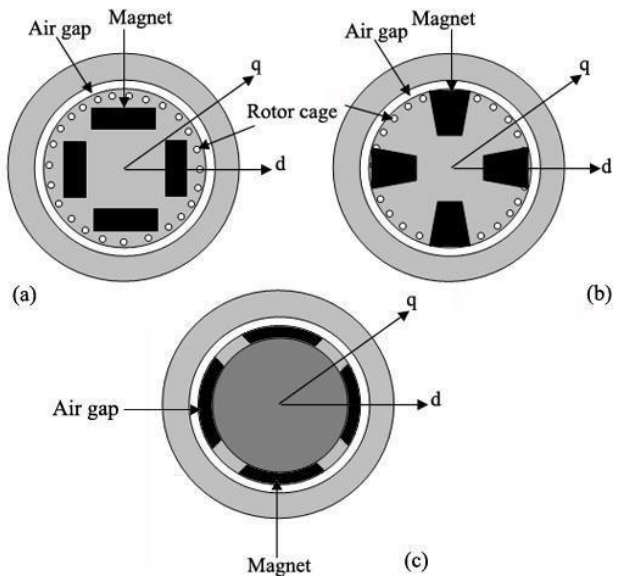


Figure 1.5. Permanent magnet arrangements on the rotor of PM synchronous machines a) Interior magnets, b) buried magnets, c) surface mounted magnets

Figure 1.6 shows the basic magnetic morphology of the motor with magnets mounted on the surface of the rotor and an otherwise conventional stator winding. This sketch does not show some of the important mechanical aspects of the machine, such as the means for fastening the permanent magnets to the rotor, so it must be treated as a general outline. In addition, this sketch and the other sketches to follow are not necessarily to a scale that would result in workable machines.

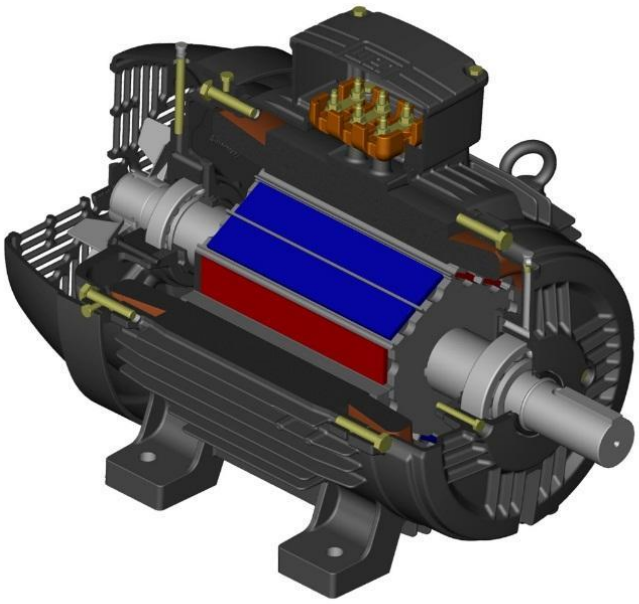


Figure 1.6. Permanent magnet synchronous machine with surface mounted permanent magnets (with 2 magnets per pole)

This figure shows an axial section of a six-pole (p=3) machine. The six magnets are mounted on a cylindrical rotor "core", or directly on shaft (for small motors), made of ferromagnetic material. Typically, this would simply be a steel shaft. In some applications, the magnets may be bonded to the steel. For applications in which a glue joint is not satisfactory (e.g. for high speed machines), some sort of rotor-banding or retaining-ring structure is required.

The stator winding of this machine is "conventional", very much like that of an induction motor, consisting of wires located in slots in the surface of the stator core. The stator core itself is made of laminated ferromagnetic material (usually silicon iron sheets). The character and thickness of these sheets are determined by operating frequency and efficiency requirements. They are required to carry alternating magnetic fields, so they must be laminated to reduce eddy current losses. This sort of machine is simple in construction. It is noteworthy that the operating magnetic flux density in the airgap is nearly the

same as in the magnets, so that this sort of machine cannot have air-gap flux densities higher than that of the remanent flux density of the magnets. If low-cost ferrite magnets are used, relatively low induction and consequently relatively low efficiency and power density are obtained. Beware, however, that with modern, high performance permanent magnet materials in which remanent flux densities can be on the order of 1.2 T, airgap working flux densities can be on the order of 1 T. With the structure for slots to carry the armature current, this may be a practical limit for air-gap flux density. It is also important to note that the magnets in this design are really in the "air gap" of the machine, and therefore are exposed to all of the time- and space-harmonics of the stator winding MMF. Because some permanent magnets have electrical conductivity (particularly the higher performance magnets), any asynchronous fields will tend to produce eddy currents and consequent losses in the magnets.

Figure 1.7. Permanent magnet synchronous machine with interior permanent magnets

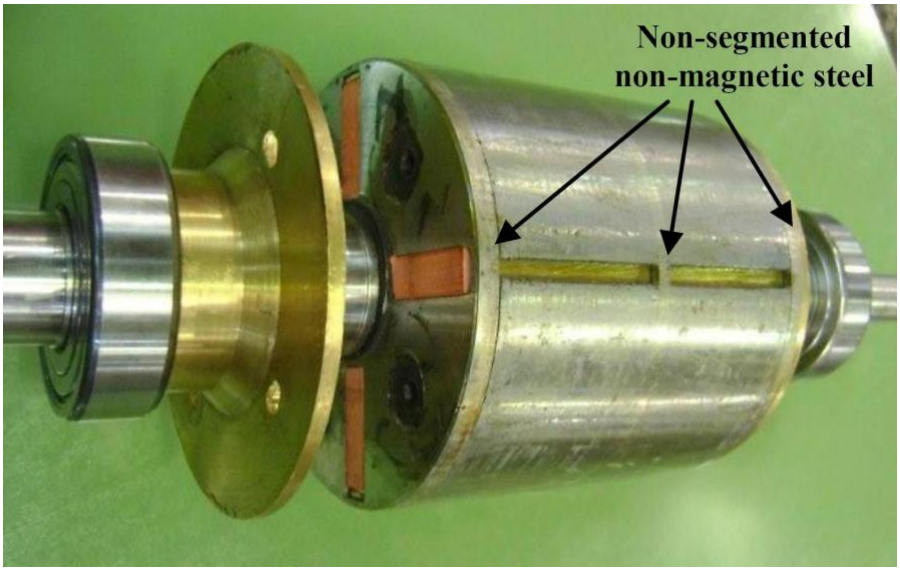


Figure 1.8. Permanent magnet synchronous machine with buried permanent magnets

Interior and buried magnet designs have been developed to counter several apparent or real shortcomings of surface mount motors:

- Flux-concentrating designs allow the flux density in the airgap to be higher than the flux density in the magnets themselves.
- In interior magnet designs, there is some degree of shielding of the magnets from high order space harmonic fields by the pole pieces.
- There are control advantages to some types of interior magnet motors.
- Some types of internal magnet designs have (or are claimed to have) structural advantages over surface-mount magnet designs.

The geometry of one type of interior magnet motor and buried magnet motor is shown in Fig. 1.7 and Fig. 1.8, respectively. A four-pole machine is shown. Typically, one does not expect flux concentrating machines to have small pole numbers, because it is difficult to get more area inside the rotor than around the periphery. On the other hand, a machine built in this way, but without substantial flux concentration, will still have saliency and magnet shielding properties. At first sight, these machines appear to be quite complicated to analyse, and that judgement seems to hold up.

The main parts of any permanent magnet synchronous machines are:

- The stator slotted magnetic core,
- The stator electric winding,
- The rotor magnetic core,
- The permanent magnets,
- The rotor shaft,
- The stator frame with bearings,
- The cooling system,
- Housing.

This section contains a brief introduction to switched reluctance motor (SRM) and its principle of operation. The key to understanding any machine is the principle of the torque production. The implications of machine operation and its salient features are inferred from the torque expression. The torque expression requires a relationship between machine flux linkages or inductance and the rotor position. The machine operation of torque vs. speed is derived from the inductance vs. rotor position characteristic of the machine, and, in line with other machines, the dynamic equivalent circuit for SRM is formulated. Various configurations of the rotary SRM, including single-phase machines, exist. The single-phase machines have applications for low performance but high-volume purposes.

Since 1969, a variable reluctance motor has been proposed for variable speed applications. Even though this machine is a type of synchronous machine, it has certain novel features. It has wound field coils of a DC motor for its stator windings and has no coils or magnets on its rotor. Both the stator and rotor have salient poles; hence the machine is referred to as a doubly salient machine. Such a machine is shown in Figure 1.9. The rotor is aligned whenever diametrically opposite stator poles are excited. In a magnetic circuit, the rotor "prefers" to come to the minimum reluctance position at the instance of excitation. While two rotor poles are aligned to the two stator poles, another set of rotor pole is out of alignment with respect to a different set of stator poles. Then, this set of stator poles is excited to bring the rotor poles into alignment. Likewise, by sequentially switching the currents into the stator windings, the rotor is rotated. The movement of the rotor, and thus the production of torque and power, involves switching of currents into stator windings when there is a variation of reluctance; therefore, this variable speed motor drive is referred to as a switched reluctance motor drive.

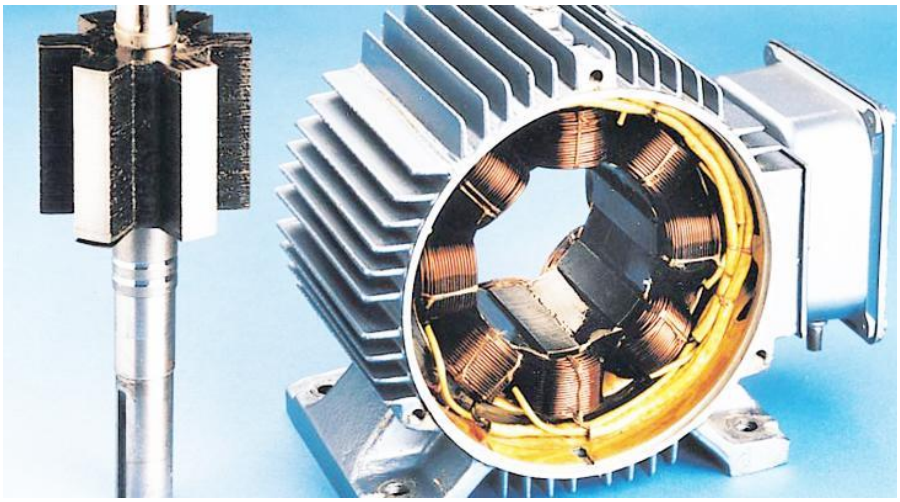


Figure 1.9. Synchronous reluctance machine

The main parts of any synchronous reluctance machines are:

- The stator magnetic core with salient poles,
- The stator electric winding,
- The rotor magnetic core with salient poles,
- The rotor shaft,
- The stator frame with bearings,
- The cooling system,
- Housing.

Usually the stator and the rotor are made of different number of salient poles. As an example, different combinations of stator and rotor number of poles are presented in Fig. 1.10.

a) 8/10 poles b) 16/12 poles c) 24/18 poles

Figure 1.10. Synchronous reluctance motor configurations

2.1.3. Direct Current Machines (DCM)

From a historical point of view, the DC machine was the earliest electromechanical energy conversion device and heralded the dawn of the electrical age. The famous copper-disk experiments of Faraday led to further inventions that contributed to the evolution of the DC machine into first electric-energy source used for illumination purposes.

The most distinctive feature of the DC machine is its versatility. The machine is reversible, so it can operate either as a generator converting mechanical energy into electrical energy in the form of direct current and voltage, or as a motor, converting electrical energy into useful mechanical work. DC generators are not in widespread use at present because AC generation, transmission, and distribution are more advantageous from an economical point of view. DC generators can be used in situations where electric-energy consumption takes place very close to the generation site, and where output voltages are required to follow closely pre-specified patterns. The area of latter application can also be met by solid-state-controlled rectification devices.

The operating characteristics of DC motors offer distinct advantages that make them attractive for many industrial applications. A wide variety of speed-torque characteristics can be obtained as a result of various combinations of separately excited, series, shunt, and compound-field winding connections. Wide ranges of speed and precise control can be easily obtained using systems of DC machines.

A DC machine is a rotating electromechanical energy conversion device that has a stator with salient poles that are excited by one or more field windings. The armature winding of a DC machine is on the rotor, with current conducted, from or to, it by means of carbon brushes in contact with copper commutator segments. A cutaway view of a 2-pole DC motor is shown in Fig. 1.11.

Figure 1.11. 2-pole wound stator DC motor

The armature windings consist of many coil sides placed on the rotor with the conductors parallel to the shaft. The field windings are fed with DC currents, and as a result the air-gap flux is almost constant under each of the salient poles. In generator operating mode, the rotor is turned at a constant speed, and as a result induced voltage appear in the armature coils.

The induced voltages are alternating and must be rectified to produce direct current. Rectification is traditionally carried out using a commutator, which is a cylinder mounted on the rotor and formed of copper segments insulated from each other and from the rotor shaft.

Commutator segments are in contact with stationary carbon brushes. The commutator is essentially a mechanical full-wave rectifier. The magnetic field established by the DC in the field winding is stationary with respect to the stator. The armature currents create a stationary magnetic-flux distribution whose axis is at right angle to that of the field flux. The interaction of the two flux distributions creates the torque in the DC machine.

In some newer topologies the wound stator excitation winding can be replaced with permanent magnets and the motor becomes permanent magnet DC commutator motor. A view of this motor is presented in Fig. 1.12.

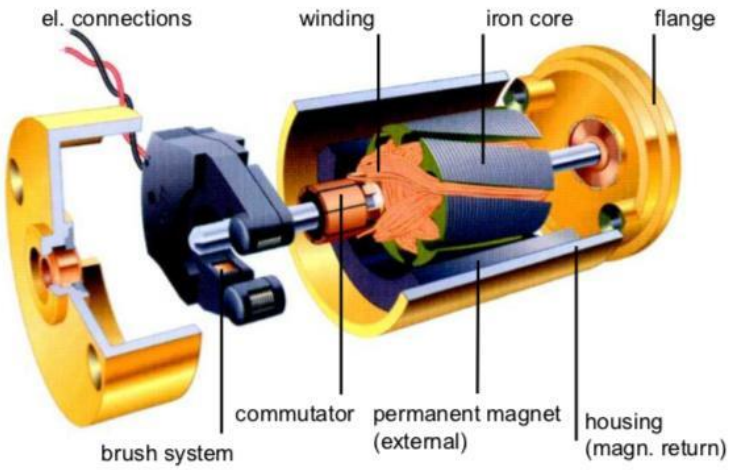


Figure 1.12. 2-pole permanent magnet DC commutator motor

The main parts of any type of DC motor are:

- The stator magnetic core with salient poles and winding or stator core with permanent magnets,
- The rotor magnetic core with slots,
- The rotor shaft,
- The stator frame with bearings,
- The cooling system,
- Housing.

2.2. Virtual Assembling of Electrical Machines

The working environment for this exercise is a factory hall with shelves and assembling bench. A presentation of this environment is shown in Fig. 1.13. A view of the assembling bench is shown on Figure 1.14. The parts for all six machines are placed on the shelves as presented on Fig. 1.15, Fig. 1.16 and Fig.1.17.

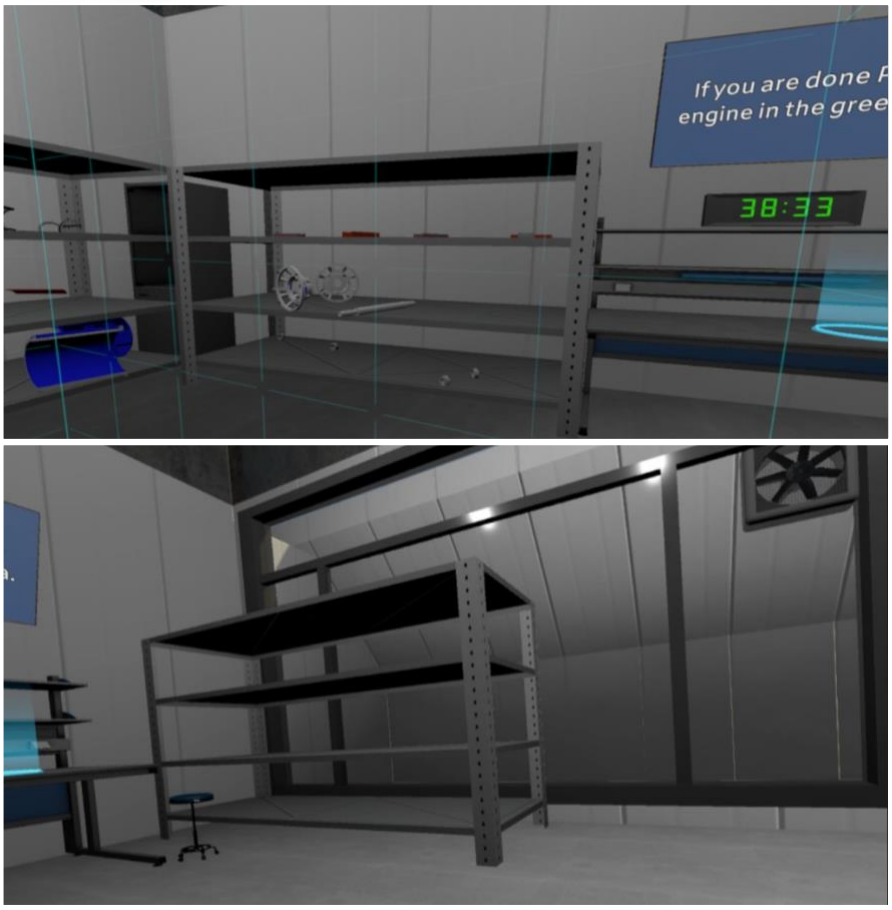


Figure 1.13. Presentation of the working environment for Scenario 1 – Construction of electrical machines

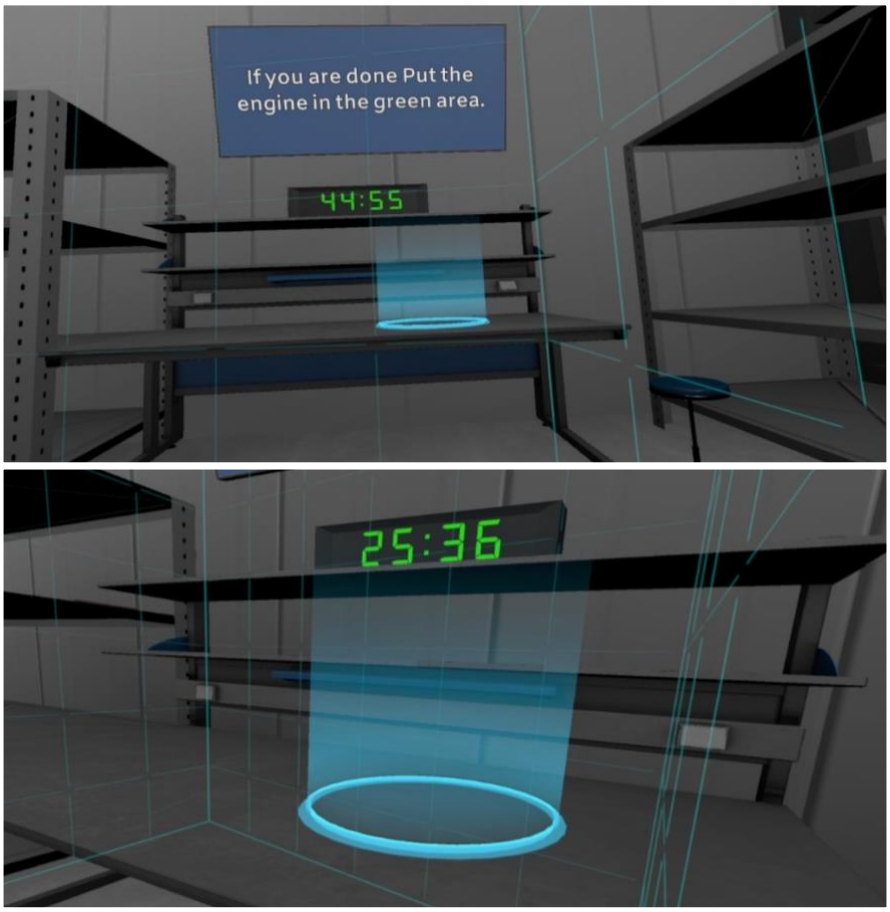


Figure 1.14. Presentation of the assembling bench for Scenario 1 – Construction of electrical machines– Construction of

Figure 1.15. Presentation of the shelves with the electric machine parts for

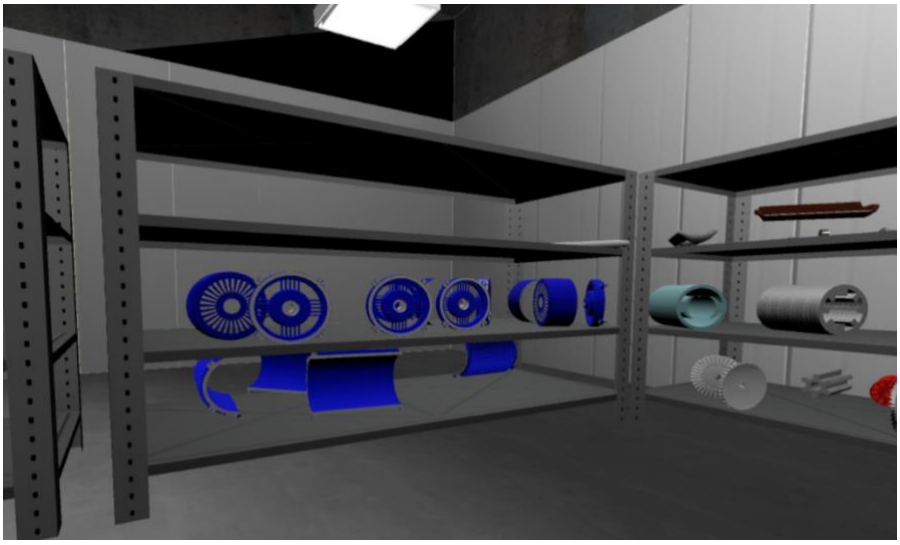


Figure 1.16. Presentation of the shelves with the electric machine parts for

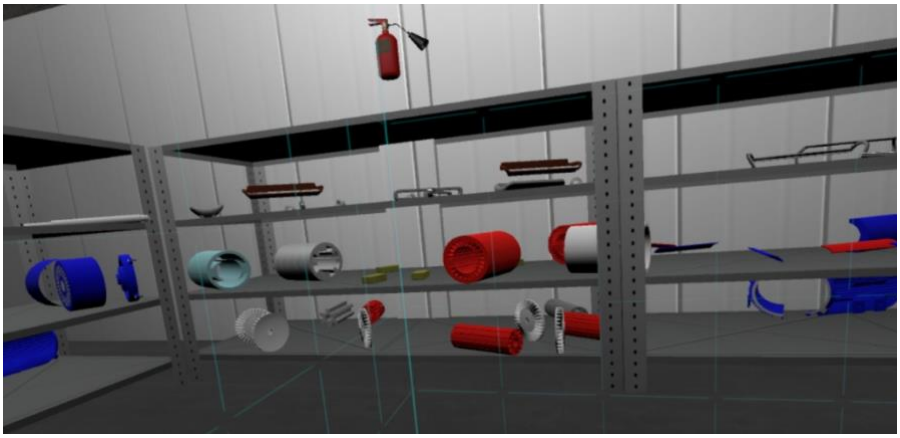


Figure 1.17. Presentation of the shelves with the electric machine parts for

Each student will be given the task to assemble a certain type of electrical machine selected from the list of 6 machines that were previously described. The parts, using the VR handles, should be picked up from the shelves and placed on the working bench. A view of the handles in the VR environment is shown in Fig. 1.18.

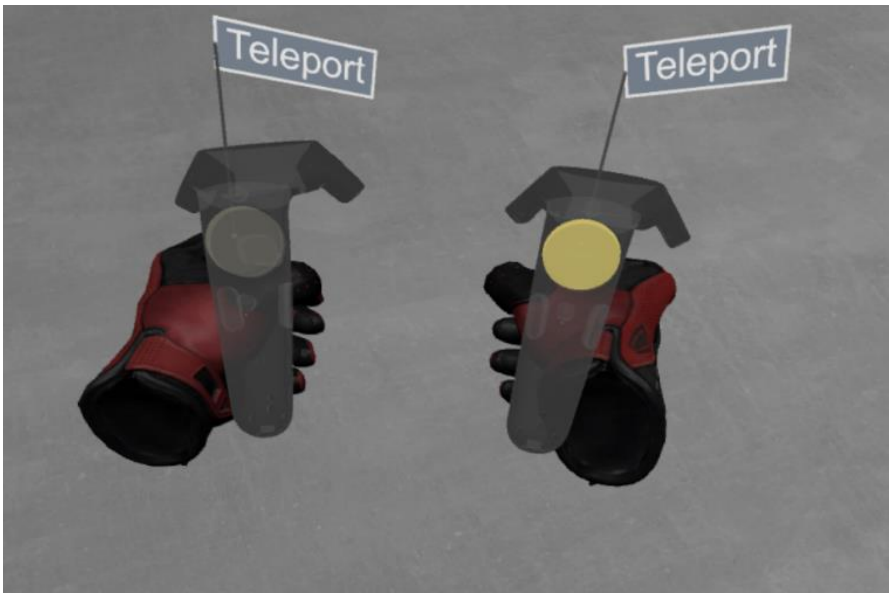
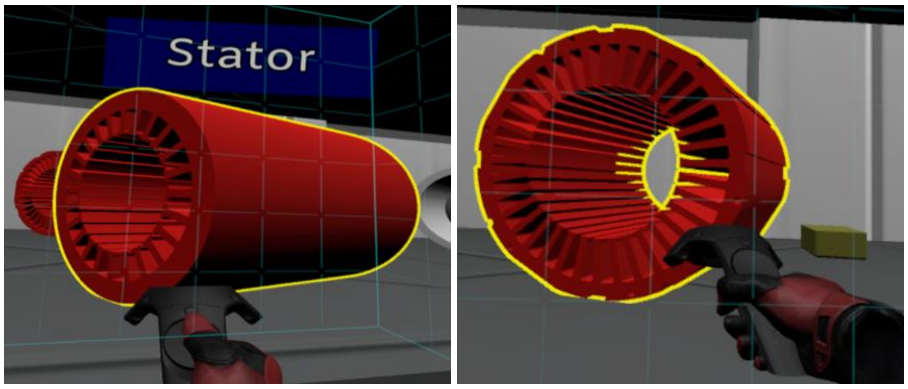


Figure 1.18. Presentation of the two handles in VR environment seen with

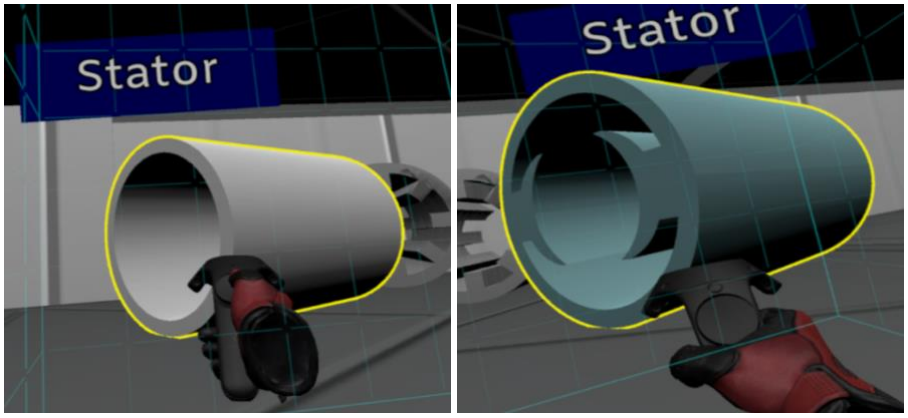
With those two handles the user can move around the working area, pick up parts from the shelves and assemble the machines. The big round button on the top of the handle (1) is used to move around the working area (teleport). The trigger on the bottom of the handle (7) is used to pick up the motor parts and place them on the working place, as shown in Fig. A.1. To pick up the part from the shelves it is necessary to move the handle very close to the part that the user wants to select. Once the handle is close enough the part will be highlighted with a yellow border line; at that stage it is necessary to pull the trigger and keep it in that position until the user wants to put it on the working table; once the trigger is released the part will also be released and placed. Presentation of selected stator cores is shown in Fig. 1.19, Fig. 1.20, and Fig. 1.21.

Presentation of selected rotor cores, shafts, and bearings is shown in Fig. 1.22, Fig. 1.23, Fig. 1.24, and Fig. 1.25. Stator and rotor windings, rotor bars and shorting rings, as well as commutator are shown in Fig. 1.26, Fig. 1.27, and Fig. 1.28. The presentation of the selected permanent magnets for two motor types are presented in Fig. 1.29 and Fig. 1.30. Presentation of the top and bottom motor housing and front and back housing cover are shown in Fig. 1.30 and Fig. 1.31, respectively. As a hint to the user when the handle is placed close enough to the motor part the description of the part appears nearby.



a) Induction motor b) Permanent magnet synchronous motor

Figure 1.19. Presentation of selected stator iron core



a) Permanent magnet DC motor b) Wound stator DC commutator motor

Figure 1.20. Presentation of selected stator iron core

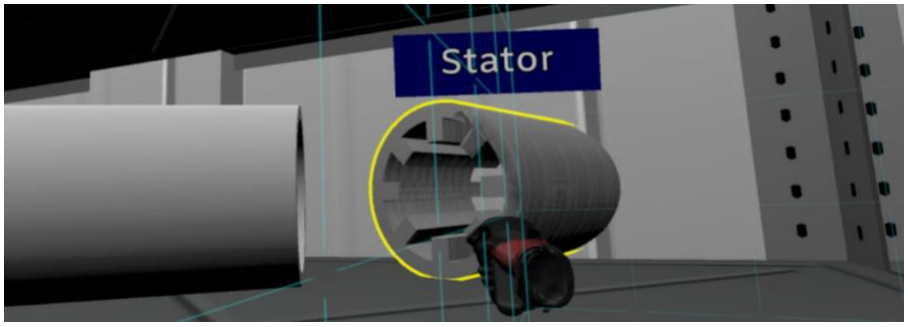
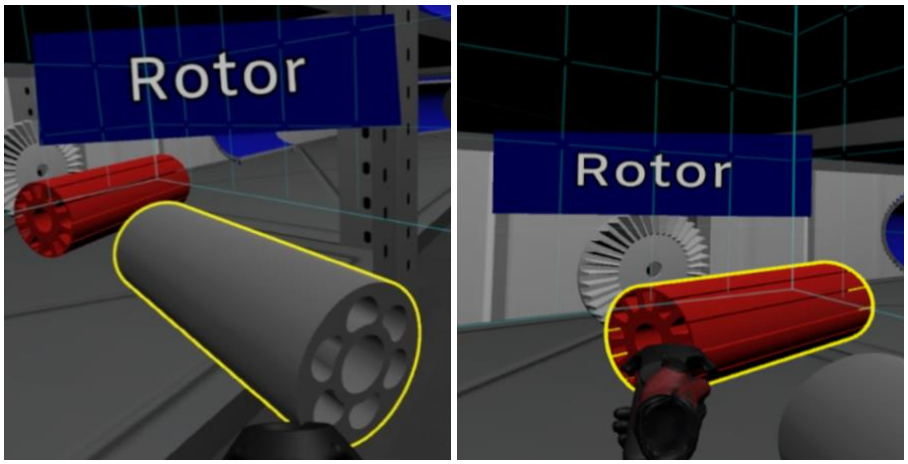
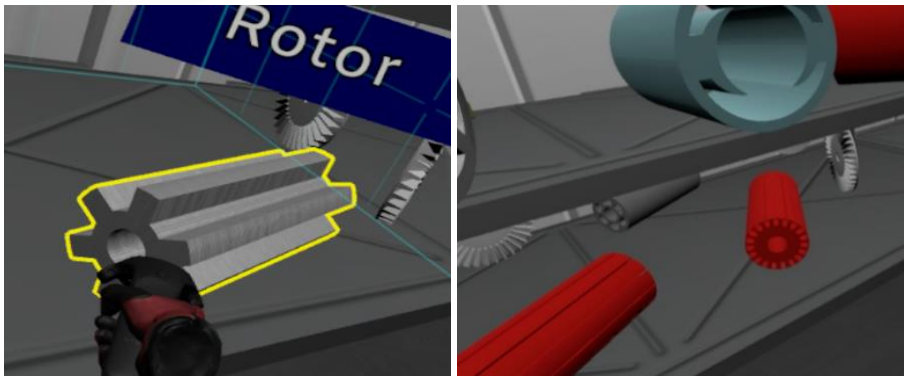


Figure 1.21. Presentation of selected stator iron core for reluctance motor



a) Permanent magnet synchronous motor b) Wound stator DC commutator motor

Figure 1.22. Presentation of selected rotor iron core



a) Reluctance motor b) Induction motor

Figure 1.23. Presentation of selected rotor iron core

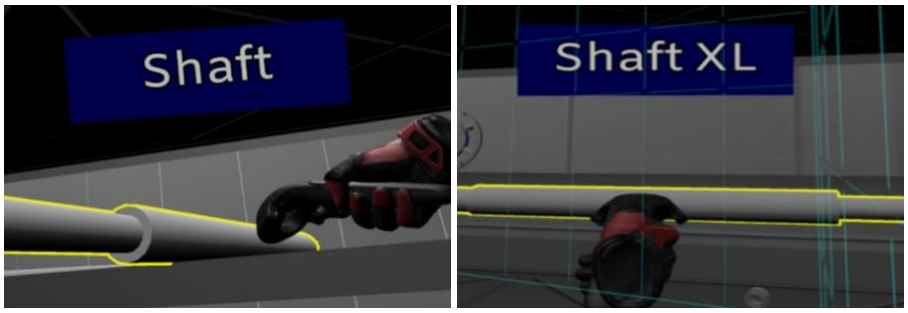


Figure 1.24. Presentation of selected shafts

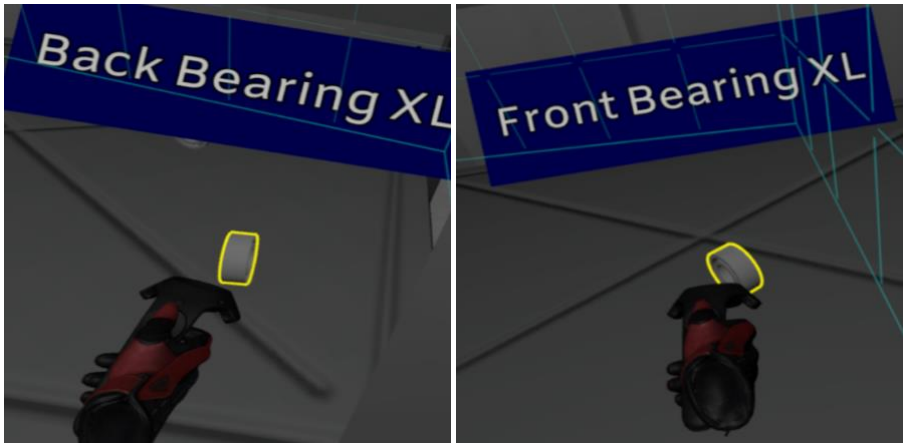


Figure 1.25. Presentation of selected bearings

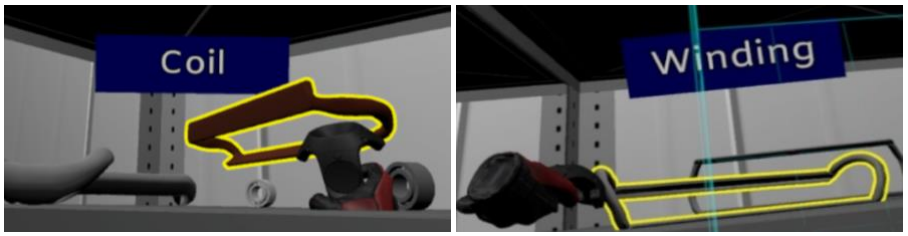


Figure 1.26. Presentation of selected coils and windings

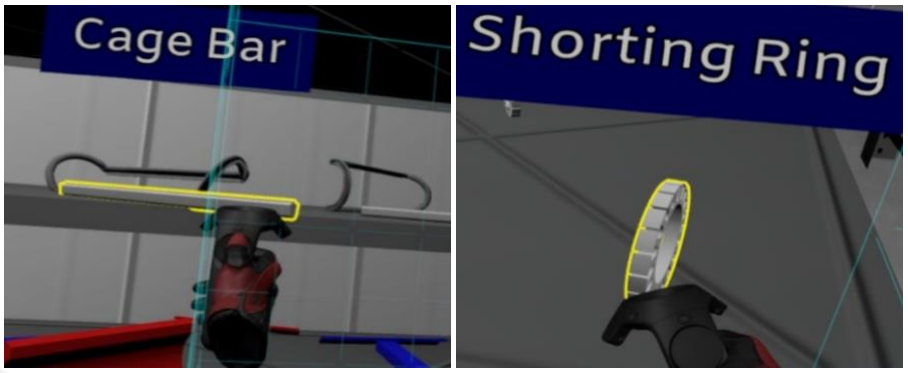


Figure 1.27. Presentation of selected cage bars and shorting rings for induction motor squirrel cage

Figure 1.28. Presentation of selected commutator for wound stator DC motor and PM DC commutator motor

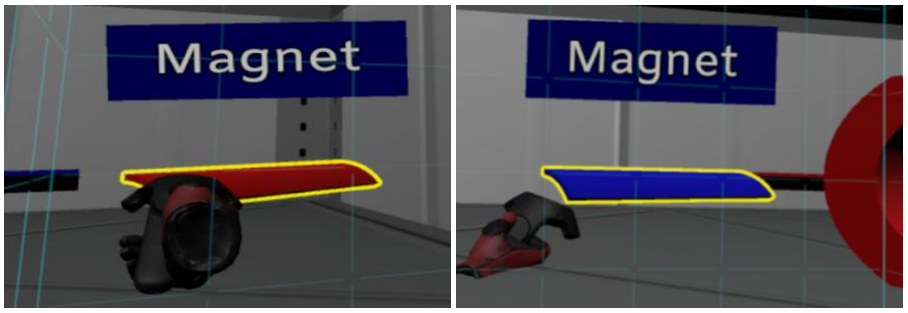


Figure 1.29. Presentation of selected permanent magnets for permanent magnet synchronous motor

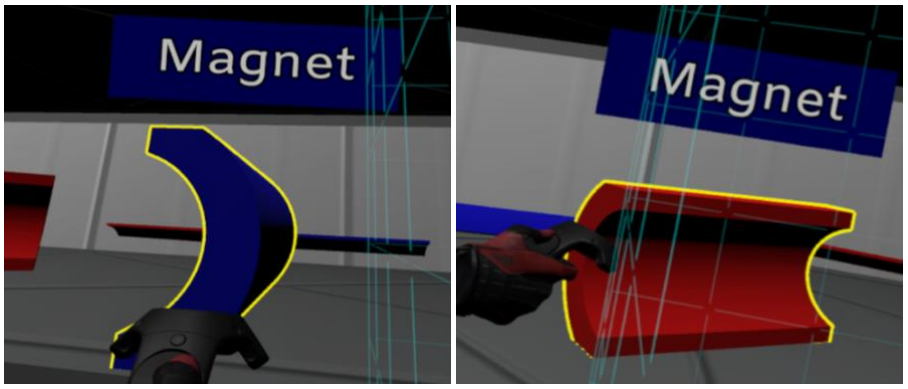


Figure 1.30. Presentation of selected permanent magnets for permanent magnet DC motor

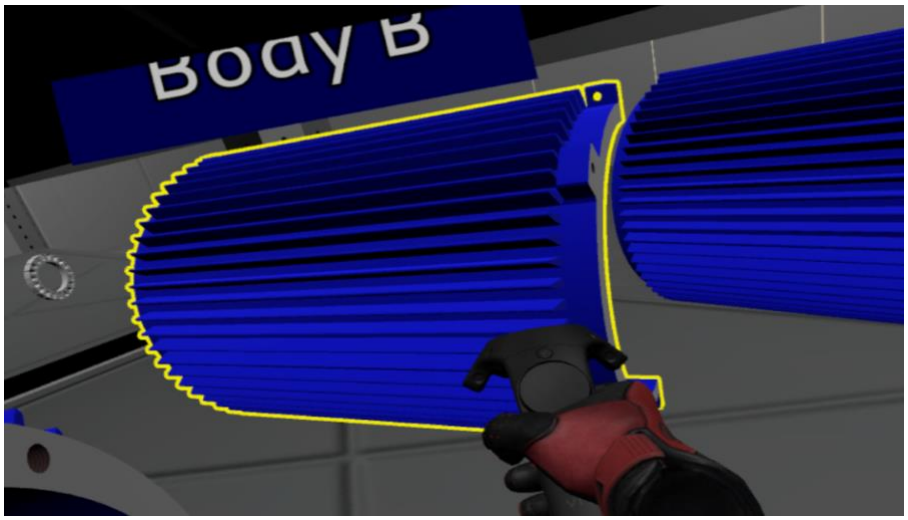


Figure 1.31. Presentation of selected bottom and top motor housing

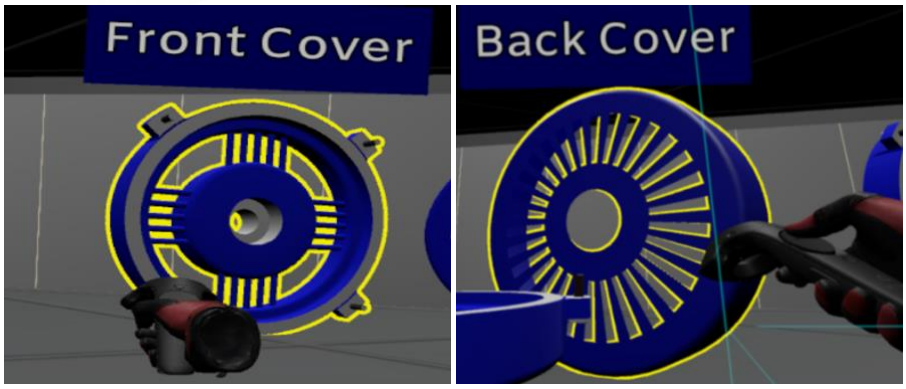


Figure 1.32. Presentation of selected front and back motor housing cover

Once all the parts are placed on the working table the user can proceed to the construction of the electrical machine. First the user should construct the rotor. This means that the shaft should be mounted on the rotor iron core, as well as the two bearings. This can be realized in such a way that when the rotor shaft is close to the correct position it will stick to the rotor iron core. If the rotor has a winding, the winding should be mounted and if the motor has permanent magnets, the magnets should be mounted. Additionally, when the motor has a commutator then the commutator also has to be mounted. Afterwards the user should proceed with the construction of the stator. The stator winding should be assembled in the stator slots, or on the stator poles for DC motor and reluctance motor. If the motor has only permanent magnets on the stator, then only the permanent magnets should be placed on the stator core (for permanent magnet DC motor).

2.2.1. Permanent Magnet Synchronous Motor (PMSM)

The parts for this motor that should be assembled are:

#	Part	Number of pieces
1	Stator core with 36 slots	1
2	Stator winding	1
3	Rotor iron core	1
4	Motor shaft	1
5	Permanent magnets	6 (3N & 3S)
6	Bearings	2
7	Housing (set)	1

Table 1.1. Permanent magnet synchronous motor

Presentation of the motor parts is shown in Table 1.2.

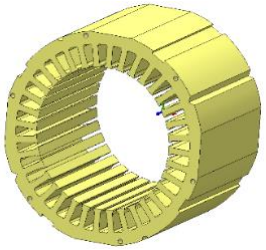
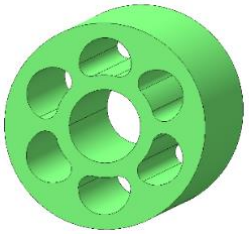
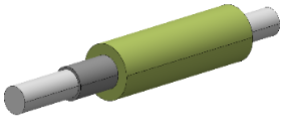
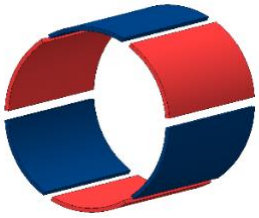
#	Part	View
1	Stator core with 36 slots	
2	Rotor iron core	
3	Motor shaft	
4	Permanent magnets	

Table 1.2. View of the main motor parts

All the necessary parts are placed on the shelves of the VR assembling room. The user should start the exercise by taking the parts from the shelf and move them to the assembling table. First, the user will insert the shaft in the rotor core and then should add the bearings. Later, the permanent magnets have to be placed in the correct position and order on the rotor core. In the next step, the stator windings should be placed in the slots of the stator core. The following step is to put the whole rotor in the bore of the stator core and afterwards the top and bottom housing part to be added to the assembled motor. With this last step, the first part of the exercise is completed.

2.2.2. Induction Motor (IM)

The parts for this motor that should be assembled are:

#	Part	Number of piec-
1	Stator core with 24 slots	1
2	Stator winding	1
3	Rotor iron core with 19 slots	1
4	Rotor bars	19
5	Rotor shorting rings	2
6	Motor shaft	1
7	Bearings	2
8	Housing (set)	1

Table 1.3. Induction motor

Presentation of the motor parts is shown in Table 1.4.

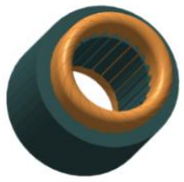
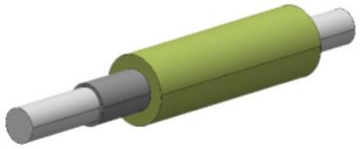
#	Part	View
1	Stator core with 24 slots and winding	
2	Rotor iron core with 19 slots	
3	Motor shaft	
4	Rotor bars and shorting rings	

Table 1.4. Induction motor

All the necessary parts are placed on the shelves of the VR assembling room. The user should start the exercise by taking the parts from the shelf and move them to the assembling table. First, the user will insert the shaft in the rotor core and then add the bearings. Afterwards, the 19 rotor copper bars are placed in the 19 rotor slots. Then, the two shorting rings are placed on each side of the rotor forming the rotor squirrel cage winding. In the next step, the stator windings should be placed in the slots of the stator core. The following step is to put the whole rotor in the bore of the stator core and afterwards the top and

bottom housing part has to be added to the assembled motor. With this last step, the first part of the exercise is completed.

2.2.3. Switched Reluctance Motor (SRM)

The parts for this motor that should be assembled are:

#	Part	Number of piec-
1	Stator core with 8 poles and concentrated	1
2	Rotor iron core with 6 poles	1
3	Motor shaft	1
4	Bearings	2
5	Housing (set)	1

Table 1.5. Switched reluctance motor

Presentation of the motor parts is shown in Table 1.6.

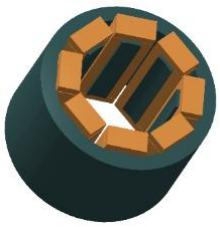
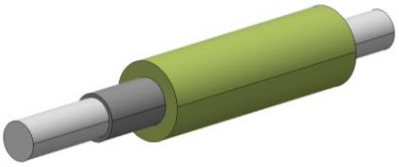
#	Part	View
1	Stator core with 8 poles and winding	
2	Rotor iron core with 6 poles	
3	Motor shaft	

Table 1.6. View of the main motor parts

All the necessary parts are placed on the shelves of the VR assembling room. The user should start the exercise by taking the parts from the shelf and move them to the assembling table. First, the user will insert the shaft in the rotor core with 6 poles and then add the bearings. In the next step, the stator windings should be placed on the 8 poles of the stator core. The following step is to put the whole rotor in the bore of the stator core and afterwards the top and bottom housing part should be added to the assembled motor. With this last step, the first part of the exercise is completed.

2.2.4. Wound Stator DC Commutator Motor (WSDCCM)

The parts for this motor that should be assembled are:

#	Part	Number of piec-
1	Stator core with two poles	1
2	Stator coils	2
3	Rotor iron core with 12 slots and armature	1
4	Motor shaft (size XL)	1
5	Commutator	1
6	Bearings (size XL)	2
7	Housing (set)	1

Table 1.7. Wound stator DC commutator motor

Presentation of the motor parts is shown in Table 1.8.

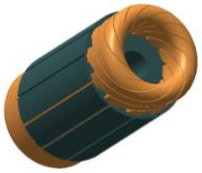
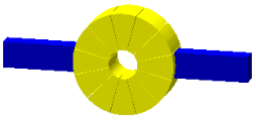
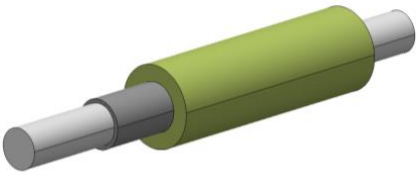
#	Part	View
1	Stator core with 2 poles and winding	
2	Rotor iron core with 12 slots and winding	
3	Commutator and brushes	
4	Motor shaft (size XL)	

Table 1.8. View of the main motor parts

All the necessary parts are placed on the shelves of the VR assembling room. The user should start the exercise by taking the parts from the shelf and move them to the assembling table. First, the user will insert the shaft in the rotor core with 12 slots and then should add the winding, the commutator and the bearings. In the next step, the stator windings should be placed on the 2 poles of the stator core. The following step is to put the whole rotor in the bore of the stator core and afterwards the top and bottom housing part should be added to the assembled motor. With this last step, the first part of the exercise is completed.

2.2.5. Permanent Magnet DC Motor (PMDC)

The parts for this motor that should be assembled are:

#	Part	Number of piec-
1	Stator core	1
2	Stator permanent magnets (1-N and 1-S)	2
3	Rotor iron core with 12 slots	1
4	Armature winding	1
5	Motor shaft (size XL)	1
6	Commutator	1
7	Bearings (size XL)	2
8	Housing (set)	1

Table 1.9. Permanent magnet DC motor

Presentation of the motor parts is shown in Table 1.10.

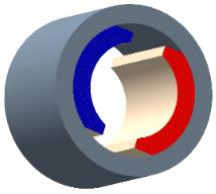
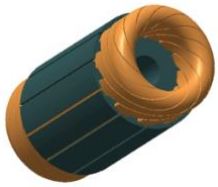
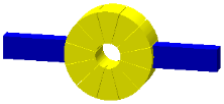
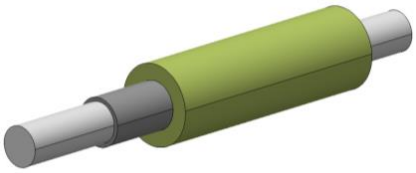
#	Part	View
1	Stator core with 2 permanent magnets	
2	Rotor iron core with 12 slots, armature winding	
3	Commutator and brushes	
4	Motor shaft	

Table 1.10. View of the main motor parts

All the necessary parts are placed on the shelves of the VR assembling room. The user should start the exercise by taking the parts from the shelf and move them to the assembling table. First, the user will insert the shaft in the rotor core with 12 slots and then should add the winding, the commutator and the bearings. In the next step, the two permanent magnets with N and S polarity should be placed on the stator core. The following step is to put the whole rotor in the bore of the stator core and afterwards the top and bottom housing part should be added to the assembled motor. With this last step, the first part of the exercise is completed.

2.2.6. Permanent Magnet Generator (PMG)

The parts for this generator machine that should be assembled are:

#	Part	Number of piec-
1	Stator core	1
2	Stator Winding	1
3	Rotor permanent magnets (2-N and 2-S)	4
4	Rotor iron core	1
5	Motor shaft	1
6	Bearings	2
7	Housing (set)	1

Table 1.11. Permanent magnet generator

Presentation of the motor parts is shown in Table 1.12.

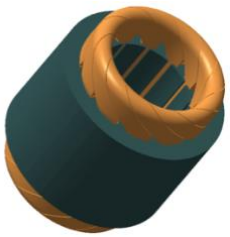
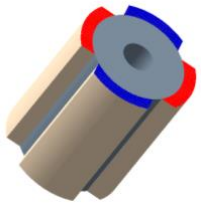
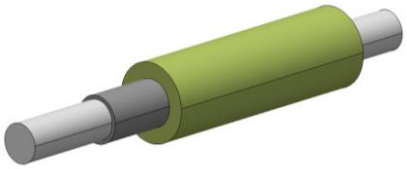
#	Part	View
1	Stator core with 12 slots and winding	
2	Rotor iron core with 4 permanent magnets (2-N and 2-S)	
3	Motor shaft	

Table 1.12. View of the main motor parts

All the necessary parts are placed on the shelves of the VR assembling room. The user should start the exercise by taking the parts from the shelf and move them to the assembling table. First, the user will insert the shaft in the rotor core, then should add the 4 permanent magnets in the sequence N-S-N-S, and the bearings. In the following step, the stator winding should be placed in the slots of the stator core. The next step is to put the whole rotor in the bore of the stator core and afterwards the top and bottom housing part should be added to the assembled motor. With this last step, the first part of the exercise is completed.

Note:
Once the motor is assembled it should be placed in the marked area on the table. If the motor is properly assembled the exercise will automatically proceed to the next level that is Operating principles of electrical machines. If the motor is not properly assembled the user will have two more chances to construct the assigned motor.

2.3. Operating Principles of Electrical Machines

In this part of the exercise a permanent magnet synchronous motor is investigated. The motor is preassembled and is placed on the test bench (as seen in Fig. 1.33), together with the other laboratory investigation equipment. The rated data of the investigated Permanent Magnet Synchronous Motor is: Un=50 V=const., nn=1000 min-1, In=11.38 A.
The testing should be realized in the following steps:

Step 1 –The motor should be connected to the Power Supply and thus prepared for testing, as shown in Fig. 1.33.

Step 2 – Turn the Power Switch ON.

Step 3 – Using the Load angle control knob start loading the motor at a fix load angle change rate (for example at an increase rate of 5˚or 10˚). After each adjusted value press the button Record Data. The recorded data should be shown on the graph as a new point or can be shown as a line connecting the previous measured points. Continue the measurements up to the moment when the motor stops working at load angle of 90 ˚; the ON/OFF switch will automatically switch to OFF position.

Step 4 –Once the motor stops a randomly selected question will appear with a multiple-choice answer. The user has to select one answer to get points.

After completing the two parts of the scenario students will be given points based on their effectiveness in the two parts of the exercise and the answer on the randomly given question at the end of the scenario. If the student assembled properly the given motor at his first attempt, they will be awarded 100% of the points for this stage, on their second successful attempt it will be 75% of the points and on their third successful attempt 50% of the points. If the student misses all three attempts, zero points will be awarded, and the exercise will be failed. For the second part of the exercise and the randomly given question the student will have only one attempt. If the student connects the motor properly and performs the investigation in a correct way, they

will be awarded the maximum number of points. The same applies for the randomly given question. For a wrong connection and wrong answer zero points will be given to the student.

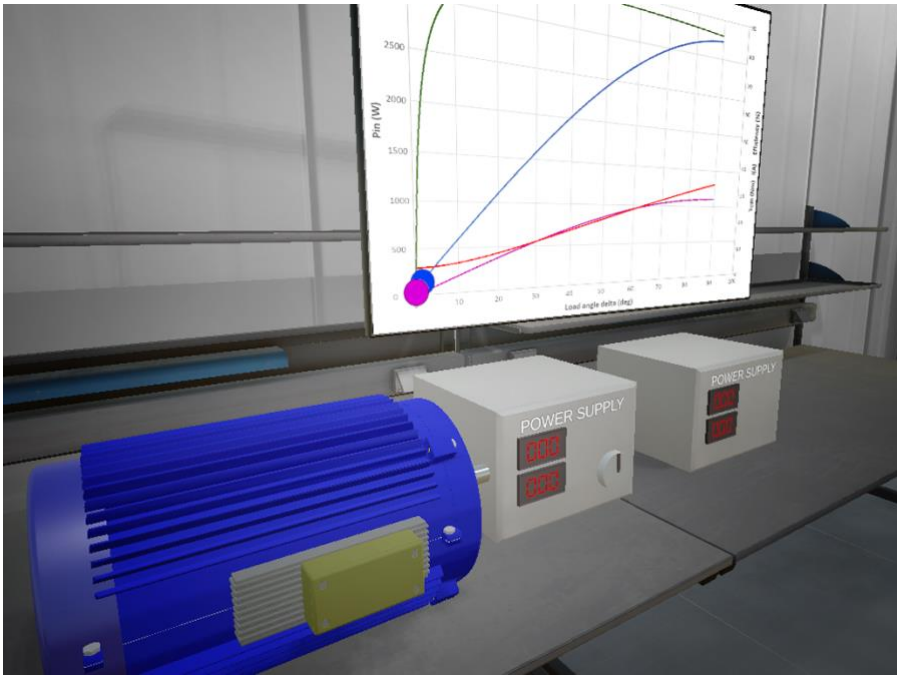


Figure 1.33. View of the test bench: investigated motor connected to the testing equipment

3. Scenario 2 - Controlling of sorting packages in a high storage warehouse.

3.1 FBD (Function Block Diagram) language

FBD (Functional Block Diagram) is a graphic language. Program execution is based on a signal flow similar to the signal flow between elements of signal processing system. The signal flow is from the output (right side) of the function or function block to the connected input (left side) of the next function or function block [1].
Graphic symbols representing individual elements of block connection diagram are rectangles and control elements connected by horizontal and vertical lines [1]. An example of an FBD language block is shown in Fig. 3.1.

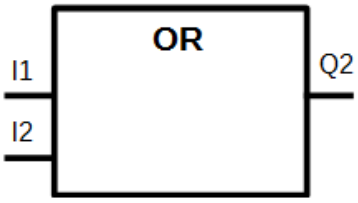


Figure 3.1. FBD - the example of the OR function

Circuit - a set of blocks (language elements) interconnected by lines [1].

Executing program rules [1]:

1. The value of any element of the circuit is not determined if the value of all its inputs is not determined.
2. Determining the value of a circuit element is not completed if the value for all its outputs has not been determined.
3. Program execution for the entire circuit is not completed if the value of outputs for all its elements has not been determined.
4. As part of the software organizational unit, program execution for the circuit should be completed before the next circuit begins, in which the outputs of the previous circuit are used.

Circuit creation rules [1]:

1. Outputs of functional blocks should not be connected.
2. If the lines connecting different elements of the circuit intersect, use the line crossing symbols without connections.

3. The structure of the program should be linear, with as few intersecting lines as possible, so that it is as coherent as possible.
4. Feedback may occur in circuits when a function or function block output is at the same time the input to another function or function block input in the circuit.
5. The order in which the circuits are executed can be changed by jump instructions.

3.2 FBD language basic blocks

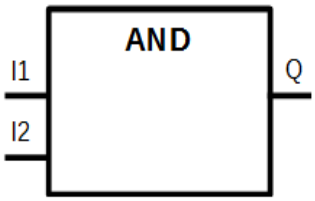
The following basic FBD language blocks can be distinguished:

- Logical function AND – for the output set at 1, all inputs must be in state 1 [2];
- Logical function OR – for the output set at 1, any input must be in state 1 [2];
- Logical function XOR – for the output set at 1, the odd number of inputs must be in state 1 [2];
- Output blocks - are used to specify an output bit; are the equivalent of LD coils. There are 2 output blocks (for Siemens S7-1200 controllers) [2]:
    - output control block,
    - negated output block.
- Bit setting and re-setting blocks:
    - setting block (set, S) – when it is activated, then the value of the variable at the OUT address is set at 1, and when it is not activated - this value remains unchanged;
    - re-setting block (reset, R) – when it is activated, then the value of the variable at OUT is set at 0, and when it is not activated - this value remains unchanged.

Logical functions have at least two (2) inputs and one (1) output. To present the principles of operation of individual logical functions, truth table which shows the output states depending on the input states can be used. Inputs and outputs in bit logic can have two states: low - marked as logic 0 (zero) and high - marked as logic 1 (one).

In the FBD graphics language, which is used to program PLC controllers, individual functions have their own graphic symbols.

Graphic symbols of basic logical functions with truth tables are shown in Fig. 3.2, 3.3 and 3.4.

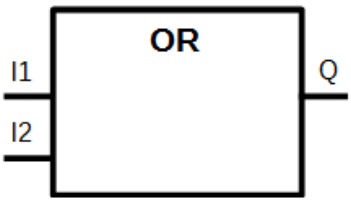


a)

I1	I2	Q
0	0	0
1	0	0
0	1	0
1	1	1

b)

Figure 3.2. Function AND:
a) FBD symbol,
b) truth table

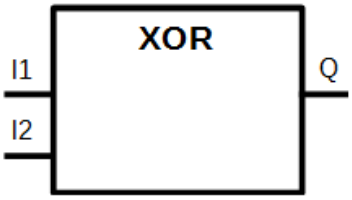


a)

I1	I2	Q
0	0	0
1	0	1
0	1	1
1	1	1

b)

Figure 3.3. Function OR:
a) FBD symbol,
b) truth table



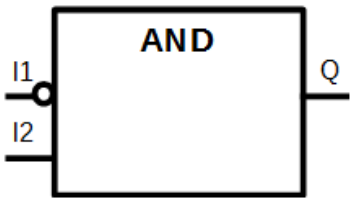
a)

I1	I2	Q
0	0	0
1	0	1
0	1	1
1	1	0

b)

Figure 3.4. Function XOR:
a) FBD symbol,
b) truth table

Input or output units may require a negation. A negated input or output reverses the signal to the opposite, i.e. it changes logical "1" to logical "0" and vice versa. An example of the negated input is shown in Fig. 3.5, the negated output is shown in Fig. 3.6

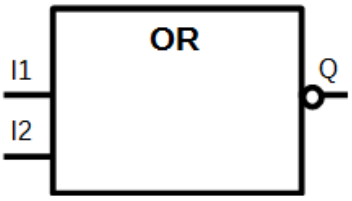


a)

I1	I2	Q
0	0	0
1	0	0
0	1	1
1	1	0

b)

Figure 3.5.



a)

I1	I2	Q
0	0	1
1	0	0
0	1	0
1	1	0

b)

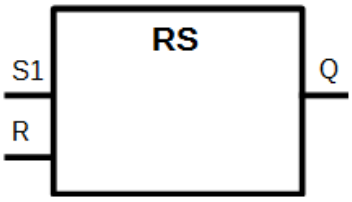
Figure 3.6.

3.3 Standard functional blocks

Bit latches are elements that enable conditional setting or deletion of a given bit of a memory space. The block instruction contains two control inputs S and R and one output. The order of these inputs determines the priority of the input and thus defines the type of bit latch [3]. There are two states of bit latches [2]:

- RS –is a set dominant latch where the set dominates. If the set (S1) and reset (R) signals are both true, the output addresses OUT will be 1.
- SR –is a reset dominant latch where the reset dominates. If the set (S) and reset (R1) signals are both true, the output address OUT will be 0.

The graphic symbols of the RS and SR bit latches with truth tables are shown in Fig. 3.7 and 3.8

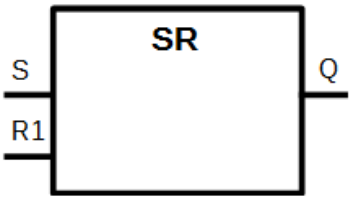


a)

S1	R	Q
0	0	previous* state
0	1	0
1	0	1
1	1	1

b)

Figure 3.7. RS bit latch:
a) FBD symbol [1],
b) truth table [2]



a)

S	R1	Q
0	0	previous* state
0	1	0
1	0	1
1	1	0

b)

Figure 3.8. SR bit latch:
a) FBD symbol [1],
b) truth table [2]

The term "previous state" means that the instruction is not executed if the signal state at the two inputs S and R1 is 0. The signal state of the operand remains unchanged.

Counters are used to count internal events in the program and internal process events, such as counting button presses or counting the operation of the proximity sensor [2].

There are three basic types of counters [2]:

- CTU –counter up.
- CTD –counter down.
- CTUD –counter up-down.

The symbols of particular counters are shown in Fig. 3.9.

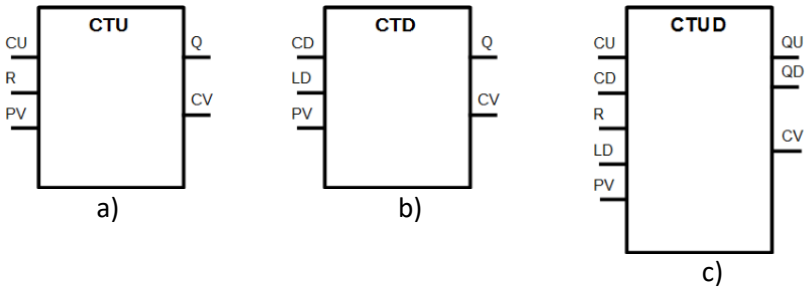


Figure 3.9. Counters:
a) up,
b) down,
c) up-down [1] [2]

Counter up CTU (Fig. 3.9a):

- CU – counting the rising slopes of the input signals,
- CV – current value,
- R – reset,
- PV – pre-set value,
- Q – output Q; at the input Q appears logical data 1, when CV=PV.

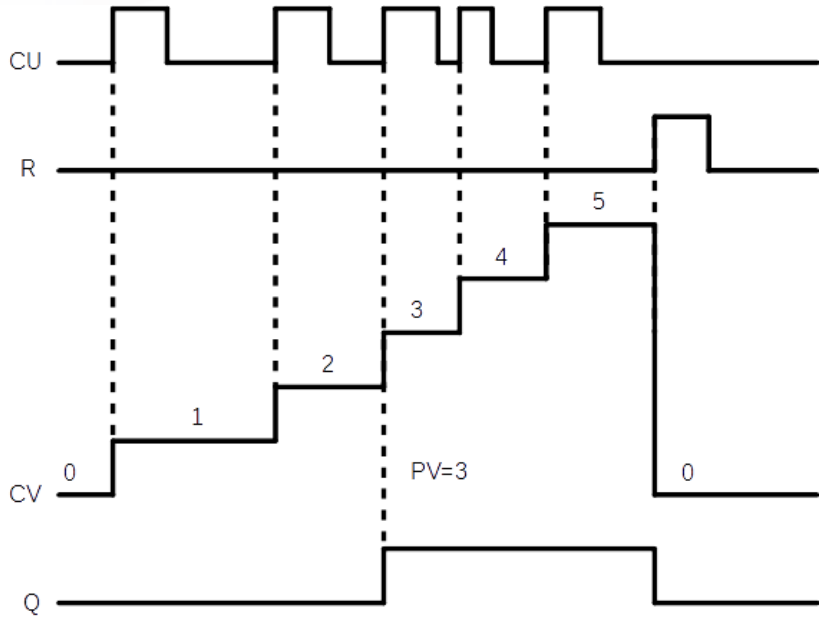


Figure 3.10. Counter up time signals [2]

The counter up operating principle can be represented in time signals. These time waveforms are shown in Fig. 3.10.

Counter down CTD (Fig. 9b):

- CD – counting the rising slopes of the input signals,
- CV – current value, a) b) c) Fig. 5: Counters: adding (a), subtracting (b), adding-subtracting (c)
- LD – load,
- PV – pre-set value,
- Q – output Q; at the input Q appears logical data 1, when CV=0.

The counter down operating principle can be represented in time signals. These time waveforms are shown in Fig. 3.11.

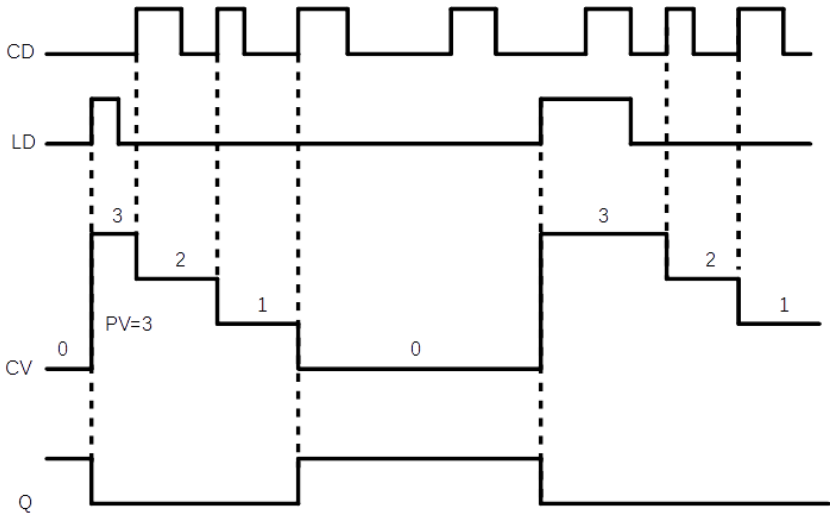


Figure 3.11. Counter down time signals [2]

Counter up-down CTUD (Fig. 9c) it is a combination of counters CTU and CTD. Therefore, it has 2 counting inputs and 2 outputs, moreover 1 reset input and 1 charging input.

The counter up-down operating principle can be represented in time signals. These time waveforms are shown in Fig. 3.12.

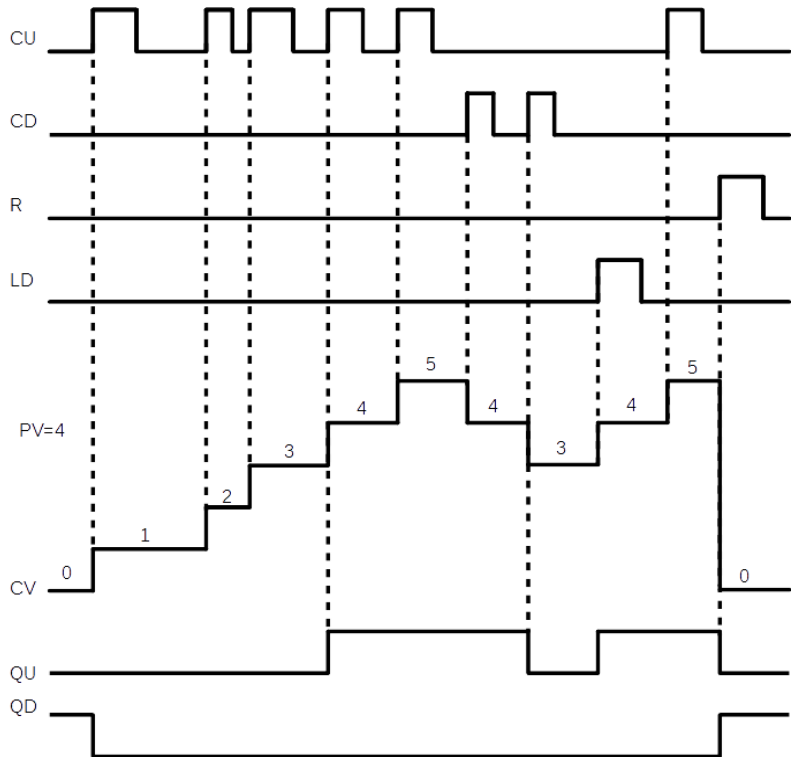


Figure 3.12. Counter up-down time signals [2]

Timers are functional blocks used for timing or switching on and off, taking into account time conditions (e.g. with delay) [1].
There are three basic types of timers [1]:

- TP – pulse,
- TON – on-delay,
- TOF – off-delay.

Symbols of particular timers are presented in Fig. 3.13.

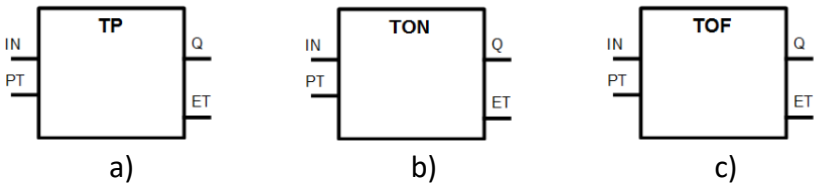


Figure 3.13. Timers:
a) TP,
b) TON,
c) TOF [1]

Timer TP (Fig. 3.13a):

- IN – timer trigger input,
- PT – pre-set time,
- ET – elapsed time,
- Q – output.

The timer TP operating principle can be represented in time signals. These time waveforms are shown in Fig. 3.14.

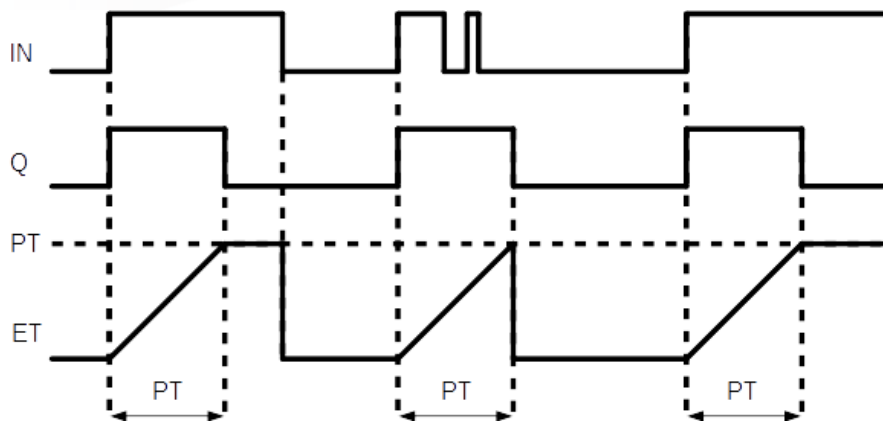


Figure 3.14. Timer TP time signals

Timer TON (Fig. 3.13b):

- IN – timer trigger input,
- PT – pre-set time,
- ET – elapsed time,
- Q – output.

The timer TON operating principle can be represented in time signals. These time waveforms are shown in Fig. 3.15.

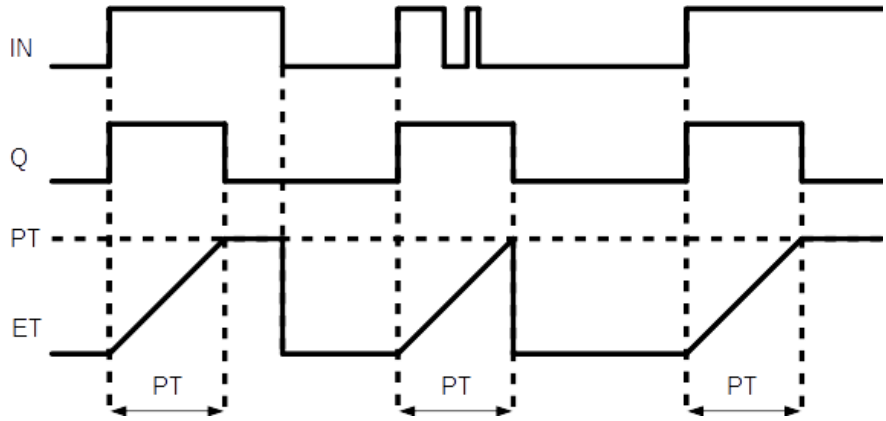


Figure 3.15. Timer TON time signals

Timer TOF (Fig. 3.13c):

- IN – timer trigger input,
- PT – pre-set time,
- ET – elapsed time,
- Q – output. The timer TOF operating principle can be represented in time signals. These time waveforms are shown in Fig. 3.16.

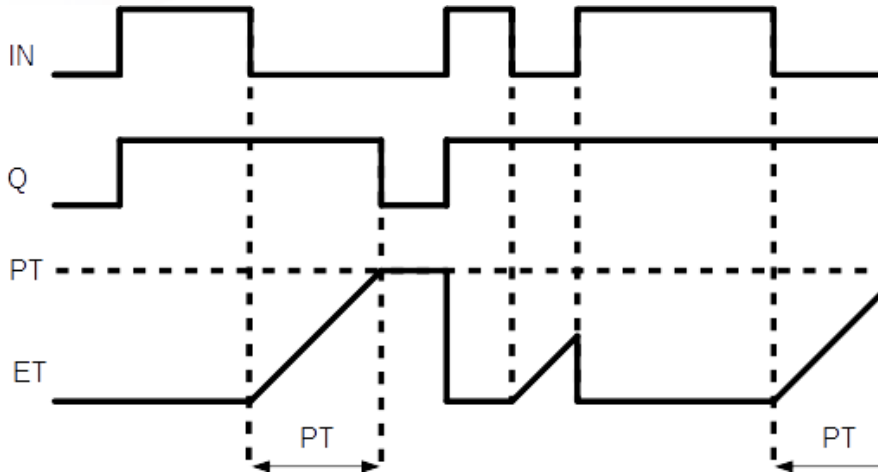


Figure 3.15. Timer TOF time signals

The comparison functions are used to compare two data values of the same type assigned to the inputs I1 and I2. If the comparison condition is met, then logic 1 appears at the output Q. Symbols of the comparison function are shown in Fig. 3.17 [2].

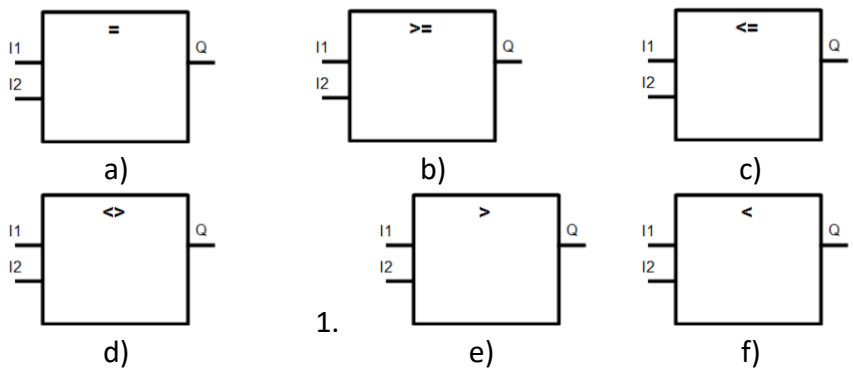


Figure 3.16. Comparison of functions with different types of relationships:
a) equal,
b) greater-equal,
c) lower-equal,
d) different,
e) greater,
f) lower [1]

3.4 Construction and Operating Principles of Controllers

Programmable Logic Controller PLC is an industrial computer that performs the following functions under control of a real-time operating system [1]:

1. **Collecting measurements (results)** using digital and analogy inputs of sensors and measuring devices;
2. **Executing user programs** containing encoded control and data processing algorithms, using the obtained data about controlled process or machine;
3. **Generating control signals** that are appropriate to the results of user program calculations and transmits them through the output modules to the components and executive devices;
4. **Transmitting data** using modules and communication links;
5. **Performing diagnostics functions** of software and hardware.

According to the definition PLC it is an industrial computer. Therefore, construction of the controller should resemble a computer set. Common elements for these two devices are undoubtedly: a microprocessor, RAM and ROM, bus, operating system (for controllers it is a real-time system). In addition, PLC is equipped with an input and output system to share information between the controller and environment. Simplified architecture of a typical programmable logic controller is presented in Fig. 3.17.

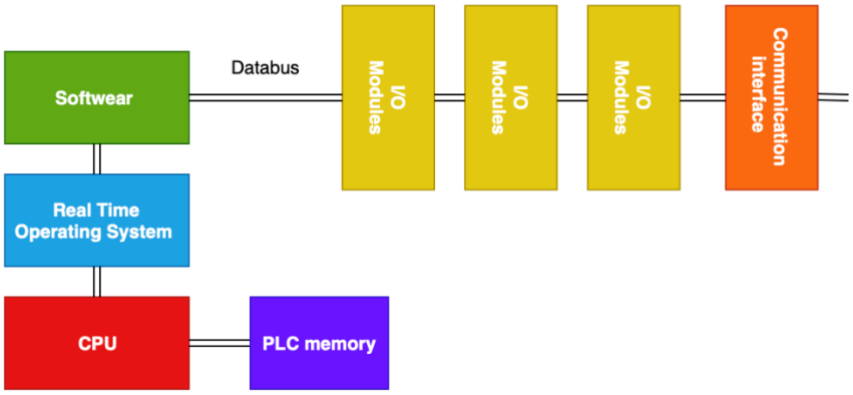


Figure 3.17. Simplified controller architecture PLC [4]

3.5 VR program description

The place to carry out exercises in the VR space in this scenario is factory space. The space has a station with a trolley moving along the tracks and a PLC simulator board. The view of the room is shown in Fig. 3.18.

Figure 3.18. Factory space

The layout of the station is shown in Fig. 3.19. The trolley is equipped with its own Drive system RL, which moves with it. The truck can move along the tracks R-L, and A and B. Transferring to adjacent tracks requires 90° rotation. Rotating platform A and Rotating platform B are used for rotation in both directions. Each platform is equipped with its own drive - Drive system A and Drive system B respectively. Each track also has limit sensors: track A - Sensor A1 and Sensor A2, track B - Sensor B1 and Sensor B2, and track RL - Sensor R and Sensor L.

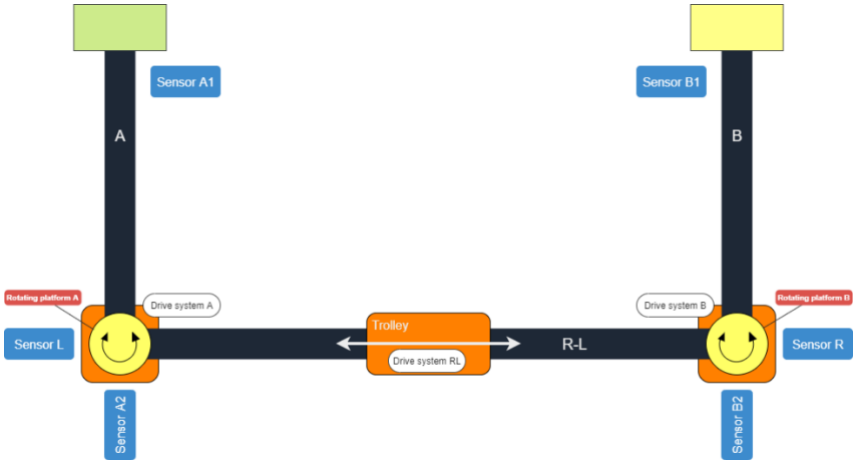
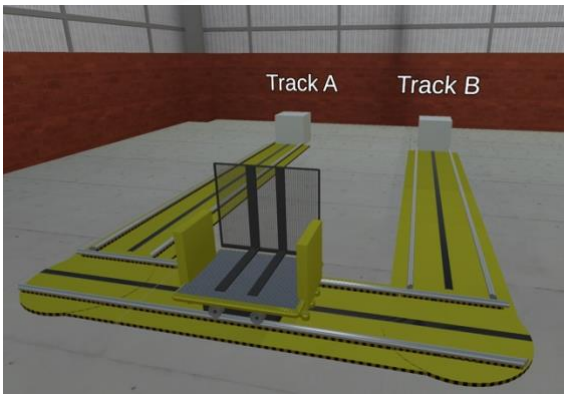


Figure 3.19. Station layout



a)

b)

Figure 3.20. a) The station; b) Above wives

The PLC simulator board consists of function blocks library, a workspace in which program blocks are placed and connected and input and output terminals. The view of the PLC simulator board is shown in Fig. 3.21. The PLC simulator has 4 binary inputs and 6 binary outputs. Sensors are connected to the inputs: Two of them informing that the trolley is on a rotating platform: Rotating platform A or Rotating platform B, and two sensors informing that the trolley has reached the end of track A or track B. Binary outputs give control signals to rotating platforms - they activate the rotation of platforms in CW and CCW directions, while two outputs activate the trolley drive (left or right).

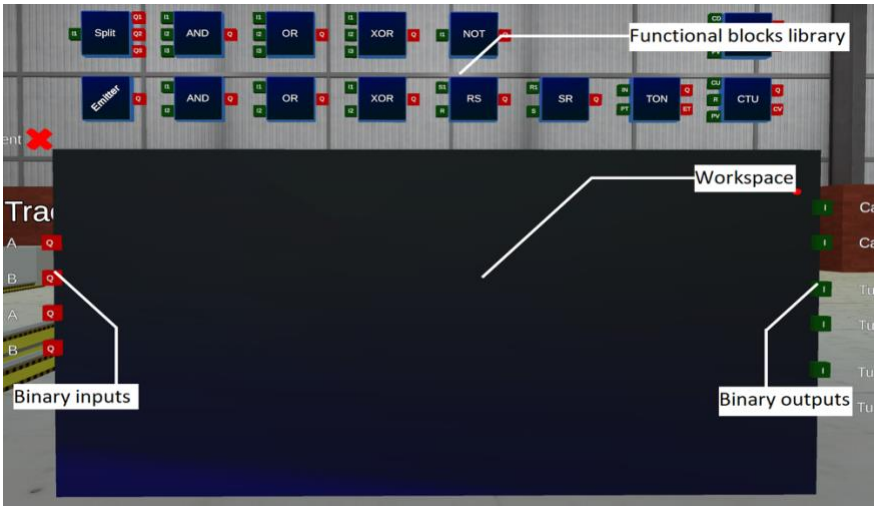


Figure 3.21. PLC simulator board

Above the PLC simulator board there is a library of function blocks. It contains the following elements:

- logical function: AND, OR and XOR,
- negating block: NOT,
- bit latches: SR and RS,
- timer: TON.

The above-mentioned elements are included in the version with two or three inputs. In addition, Split - block separating the signal and Emitter - blocking on logic output "1" are available.
The sample of PLC simulator function block symbols libraries in Fig. 3.22.

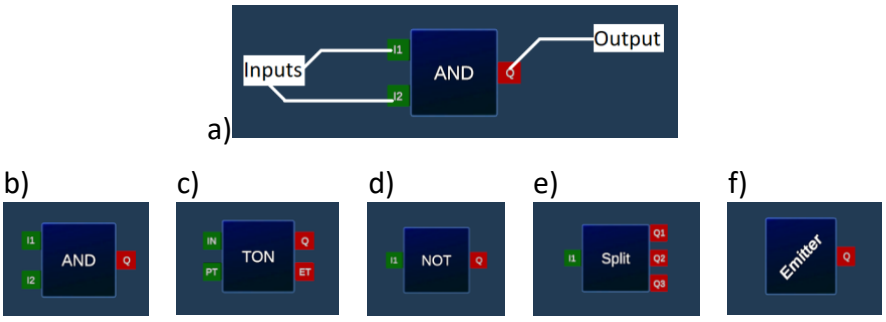


Figure 3.22. PLC simulator function block symbols:
a) function block with 2 inputs,
b) function block with 3 inputs,
c) timer TON,
d) negating block NOT,
e) Split - block,
f) Emitter

Creating an industrial application control program requires inserting appropriate function blocks into the workspace and making the correct connections between them. Blocks are downloaded from the library using a virtual hand controlled by manipulators. The block downloaded from the library should be placed in the workspace and then combined with the other blocks. It is possible to connect the output of one block with the input of the next one, while block outputs cannot be combined. However, it is possible to split the output signal using a Split - block. To run the program, it is necessary to insert the Emitter block. The trolley can be moved to the start position by Reset environment button located next to the PLC simulator board workspace.

References:

[1]. Kasprzyk J., Programowanie sterowników przemysłowych, WNT Warszawa 2006
[2]. Simatic S7 Programowalny sterownik S7-1200. Podręcznik systemu, Wydanie 04/2009
[3]. Kwaśniewski J., Sterowniki SIMATIC S7-1200 w praktyce inżynierskiej, BTC Legionowo 2013
[4]. Kwiecień R., Komputerowe systemy automatyki przemysłowej, Helion Gliwice 2013

Scenario 3 -Sorting Line with Belt

4.1. Purpose of the Scenario

In the last decades automatic sorting of waste has been a topic of interest all over the world. In the research field, numerous papers have been written on new methods, sensors and actuators for sorting waste in an efficient way.
Students are going to become familiar with recycling process, the crucial part of which is sorting waste. In particular, the students will have the opportunity to set up and use electromagnetic sensors and actuators to be used in a sorting line.
In vast majority of industries mixed waste is sorted based on conventional methods. Typically, most of the unused and waste materials comprise metal, glass, paper, plastic or biodegradable waste from the kitchen. These materials can be recycled for further use and the first step towards recycling is waste sorting.
By building a sorting line, the user can learn how to set and properly use the sensors and actuators available in the exercise.

4.2. Introduction

There are two subcategories of sorting, hence two correlating scenarios to choose from: domestic waste and industrial waste sorting. The choice can be made in the main menu shown in Fig. 4.1. Belt velocity and spawn rate of trash can also be adjusted.

The arrow in the second line allows to choose a scenario:

- Domestic waste.
- Industrial waste.

In the domestic waste sorting, there are three categories of materials:

- Organic waste;
- Glass (bottles);
- Plastic (food packaging).

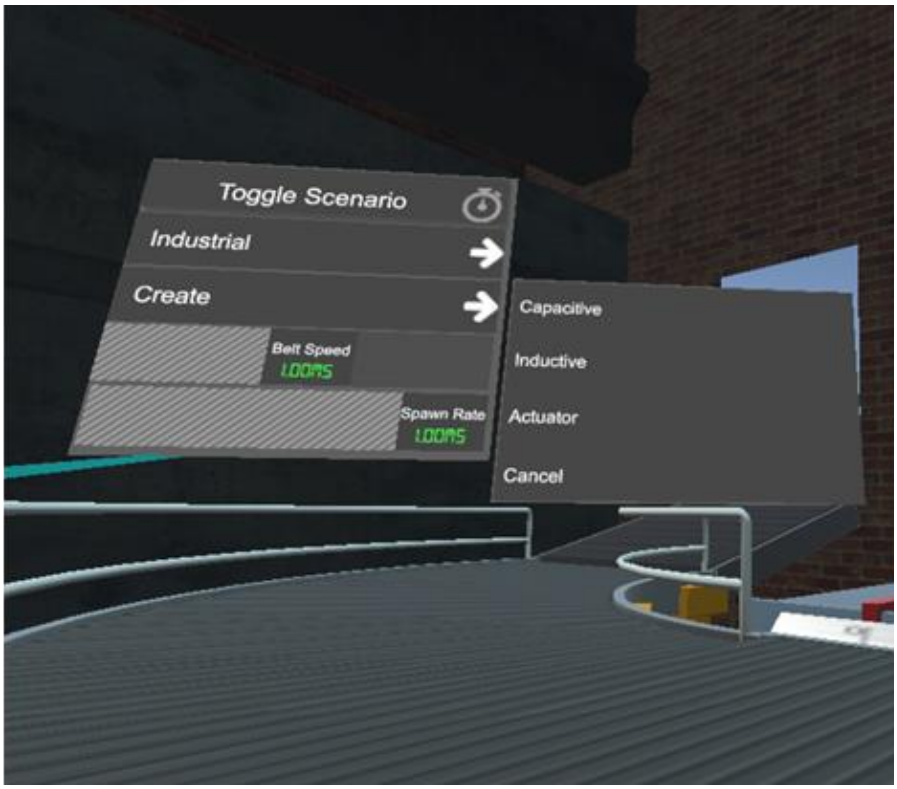


Figure 4.1. Main menu

In the industrial waste sorting, there are three types of materials:

- Ferromagnetic and non-conductive (such as ferrite in motor core and cable shielding);
- Conductive and non-ferromagnetic (such as aluminium and copper of motor bar and coils);
- Plastic (parts of the motors in plastic).

Two type of sensors can be used in this Scenario: inductive sensor and capacitive sensor. The inductive sensor is able to distinguish metallic and ferromagnetic objects while the capacitive sensor reacts to plastic, glass and organic waste. When sensors detect the material of the waste, the actuators push the sorted trash into the corresponding bin. The user has to set up the sorting line and there is no time limit for this activity.

4.3. Virtual Assembling of the Sorting Line

The sensors and actuators should be inserted by the user (by means of the button "create" in the main menu, see Fig. 4.1) and put in predefined positions. In particular, because the predefined slots are 20 cm wide, the inductive sensor with 20 cm diameter must be put in one of the predefined slots. The capacitive sensor, which is 20-60 cm in diameter, can occupy up to three predefined slots on one belt side (fed electrode) and three slots on the other belt side (grounded electrode). The actuators should be placed in predefined slots as well.
All sensors and actuators should be located in the predefined positions in the specific slots on the sorting belt; actuators should be located in front of each bin.
For the sake of an example, in Fig. 4.2 a possible configuration of the sorting line for Scenario A is represented (CS and CSG are the two plates of the Capacitive Sensor).

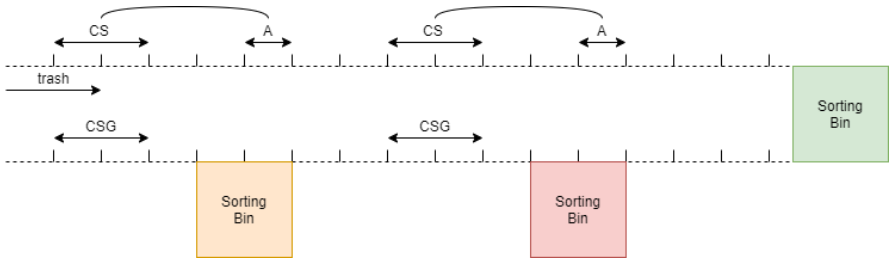


Figure 4.2. Possible configuration of the sorting line

After assembling the sorting line, the parameters of each sensor and actuator must be set up.
By clicking on each object, it is possible to adjust the relevant parameters within a given range.

4.4. Capacitive sensor

The capacitive sensor consists of two electrode plates: one is grounded, the other is fed by an AC voltage. The piece of trash to be detected and sorted passes through these plates. Due to different dielectric properties of the waste, changes in the capacity C arise and they are detected by the sensor. The sensor is shown in Fig. 4.3.

Figure 4.3. Capacitive sensor

The dimensions of the plates are variable in length. The user can set the length choosing among 20, 40 or 60 cm i.e. occupying 1, 2 or 3 slots along the belt.

The user can click on the plus sign of the sensor and a menu opens: here the user can set the magnitude and frequency of the applied voltage and the plates length.

Besides adjusting the length of plates, the frequency f and amplitude V of the applied voltage can change within the predefined range as follows:

$$10\ \text{kHz} \leq f \leq 20\ \text{MHz}$$

$$100\ \text{mV} \leq V \leq 20\ \text{V} \qquad \text{(eq. 1)}$$

In summary, for this sensor, the amplitude of the sensing current is derived from

$$\mathrm{I} = \frac{V1}{\left|\frac{1}{j\omega C}\right|} = V2\pi f C \quad [A] \qquad \text{(eq. 2)}$$

The current that the capacitive sensor is capable of detecting is in the following range:

$$50\ [\mu\text{A}] \leq \mathrm{I} \leq 10\ [\text{mA}]. \qquad \text{(eq. 3)}$$

If the output current is below 50 µA, the current is not in the detectable range so no output signal is generated, while over 10 mA the system is setting off an alarm and eventually the sensor can burn after some time (sensor overheating). However, for the current in the range of 50 µA to 10 mA, the capacitive sensor works correctly.

4.5. Inductive sensor

The inductive sensor is able to sense conductive and ferromagnetic objects. The principle for sensing conductive objects is based on eddy currents: when the coil is fed by a time-varying current (in this sensor alternating current), the eddy currents arise in the conductor, which modifies the magnetic field distribution. The principle for sensing ferromagnetic materials is based on the modification of magnetic field distribution due to the ferromagnetic object which tends to attract the field lines.

The sensor is built of an iron-cored coil, fed by AC voltage, and a conducting screen. When the coil is at no-load (no ferromagnetic

neither conductive objects to be sensed), it is characterized by a given value of the impedance. When a conductive object is placed in front of the sensor, the impedance of the coil becomes lower. When a ferromagnetic object appears in front of the sensor, the impedance of the coil becomes higher. The inductive sensor is shown in Fig. 4.4.

Figure 4.4. Inductive sensor

The user can click on the sensor and a menu opens: here the user can set the magnitude and frequency of the applied voltage.
The frequency f and amplitude V of the applied voltage can change within the predefined range as follows:

$$10\ \text{kHz} \leq f \leq 1\ \text{MHz}$$

$$100\ \text{mV} \leq V \leq 10\ \text{V}$$

(eq. 4)

In summary, for this sensor, the amplitude of the sensing current is derived from

$$I = \frac{V}{|j\omega L|} = \frac{V}{2\pi f L}\ [\text{A}]$$

(eq. 5)

The current that the inductive sensor is capable of detecting is in the following range:

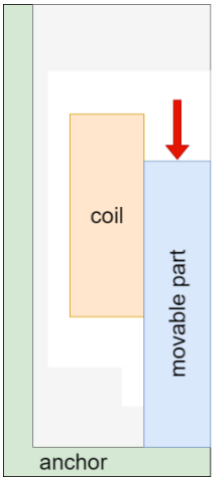
$$50\ [\mu\text{A}] \leq I \leq 10\ [\text{mA}].$$

(eq. 6)

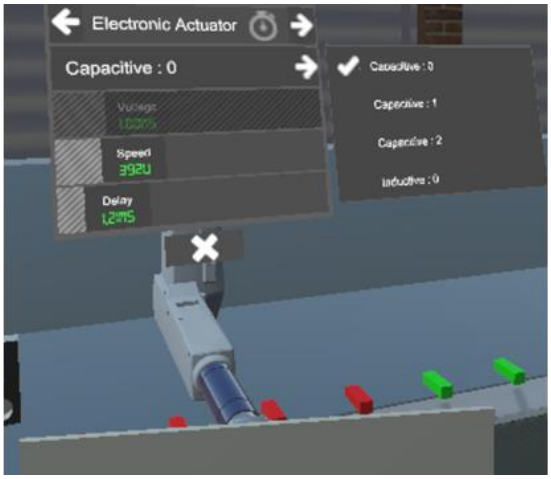
If the output current is below 50 µA, the current is not in the detectable range so no output signal is generated, while over 10 mA the system is setting off an alarm and eventually the sensor can burn after some time (sensor overheating). However, for the current in the range of 50 µA to 10 mA, the inductive sensor works correctly.

4.6. Electromagnetic actuator

The actuator is built of a magnetic circuit and a coil. When the current flows in the coil, the movable part of the actuator (in red in Fig. 4.5a) is pulled inside the actuator (movement bottom-up in Fig. 4.5a) and as a result the anchor (in green in Fig. 4.5a) pushes the piece of trash. When the current is off, the movable part exits from the actuator (downward movement in Fig. 4.5a) and the anchor is retained inside. The electromagnetic actuator as can be seen in the Scenario is shown in Fig. 4.5b.



(a)



(b)

Figure 4.5. Electromagnetic actuator

The user can click on the actuator and a menu opens: here the user can adjust the velocity of the anchor. The velocity is related to the force, which is proportional to the squared value of the current.
The actuator has to be linked to its relevant sensor by choosing one from the list of already created sensors, as shown in Fig. 4.5b.
The actuator is able to push the piece of trash into a bin if the velocity is set within the correct range of values. Otherwise the object will be pushed out of the bin or will remain on the belt.
A delay for the actuator must be set knowing the belt velocity (see main menu) and the distance between green (or red) bars on the belt side, which is 20 cm, it is possible to calculate the right delay to set.

4.7. Operating sorting line

After setting up the sorting line, the user runs it: the duration of this part of the exercise is 2 minutes. To activate or pause the Scenario, the user must click on "Toggle Scenario" in the main menu (see Fig. 4.1). The number of correctly and incorrectly sorted pieces of trash appears at the end of the exercise and the user is awarded a score based on their success rate (see Fig. 4.6).

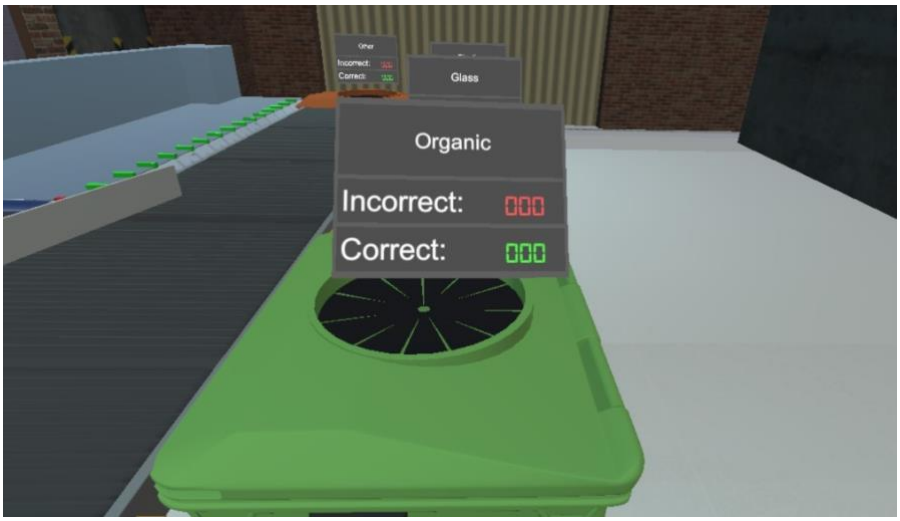


Figure 4.6. Bin for organic waste and score

Appendix A -HTC Vive: User Manual

Introduction

This guide is intended as a basic user guide to both setups, use and maintain the HTC Vive VR set. The guide contains basic instructions that need to be followed when assembling and first turning on the Vive. The controllers section contains a section describing how to navigate the VR environment. Lastly the headset section describes how to clean and maintain the headset itself. The guide is based off of the official HTC Vive user guide:

https://www.htc.com/managedassets/shared/desktop/vive/Vive

Controllers

1. Menu button
2. Trackpad
3. System button
4. Status light
5. USB charging adapter
6. Tracking sensor
7. Trigger
8. Grip button

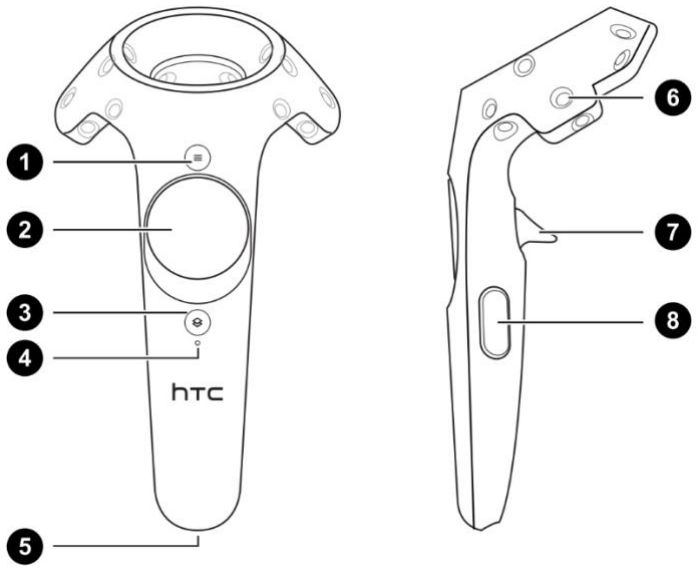


Figure A.1. Vive controller

Activation

To turn on the controller, press and hold the System button until you hear a beeping sound. To turn the controllers off, hold the System button until you hear a beeping sound. When turned on for the first time, the controllers will automatically pair with the headset.
To manually pair the controllers, launch the SteamVR app, and then go to **Settings ⇒ Devices ⇒ Pair Controller**

Status light

White light shows the controller is fully charged while charging

1. Blinking blue light, the controllers are pairing with the headset
2. Blue when the controller is paired
3. Blinking red when the power is low
4. Orange light when the controller is charging
5. Green light when the controller is active

Usage

In order to navigate the VR environment, aim a controller at the intended menu target and press the trigger button.
The trackpads can be used for movement inside VR. In order to do this, hold the trackpad which will project a teleportation indicator. Pressing the trackpad then teleports the user to the selected location.
The system button can be used to enter the SteamVR main menu from any VR environment and it can be disabled by pressing the system button a second time. The SteamVR menu does not show up on a dedicated mirroring, it will only show as a loss of resolution.

Base stations

1. Status light
2. LED lens
3. Channel indicator
4. Power port
5. Channel button
6. Sync cable port
7. Micro USB port

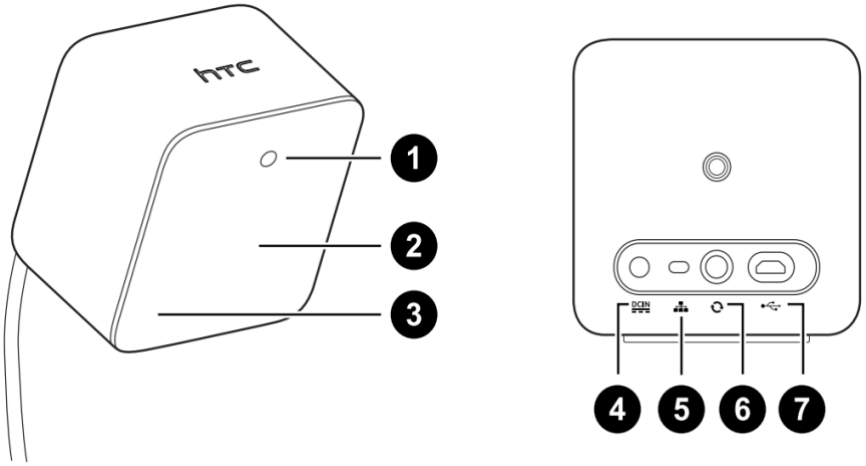


Figure A.2. Base stations

Installation

Position the base stations diagonally across the room and above your height. For proper tracking, make sure that the maximum distance between the two base stations is 5 meters and the minimum is 2 meters. Each base station has a 120- degree field of view. It is recommended that they are angled down between 30 to 45 degrees.

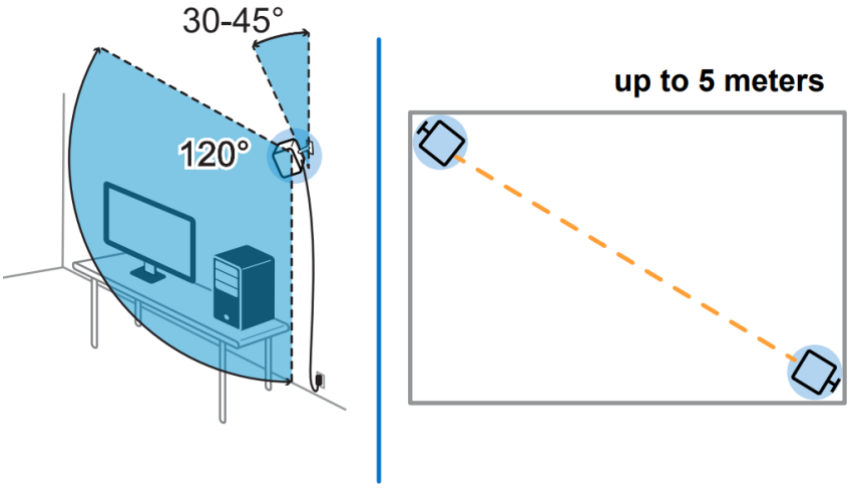


Figure A.3.

Activation

After connecting the power cable to the base station. Press the Channel buttons at the back of the base stations so that one base station is set to channel “b”, while the other is set to channel “c”.

Status light

1. Green when the base station is active.
2. Blinking green when the base station is on standby.
3. Purple when the base stations are trying to sync.
4. Blinking purple when syncing is blocked.

Headset

Lens adjustment

To adjust the interpupillary distance for the lenses, adjust the knob on the bottom left side of the headset,

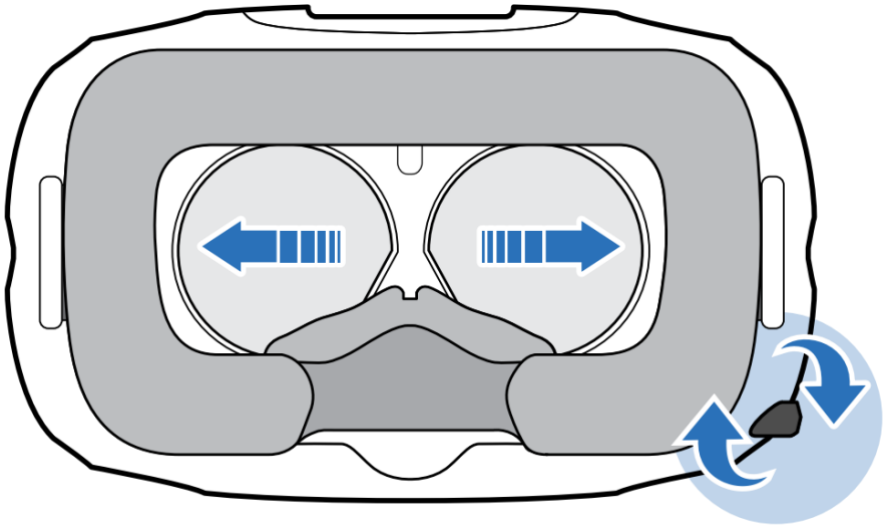


Figure A.4.

Cleaning the face cloth

In order to clean the face cushion, peel the cushion from both sides until it detaches from the headset. Then wipe the cushion with a damp smooth cloth and dry at room temperature. Do not dip, soak, scrub, wring nor bleach the face cushion.

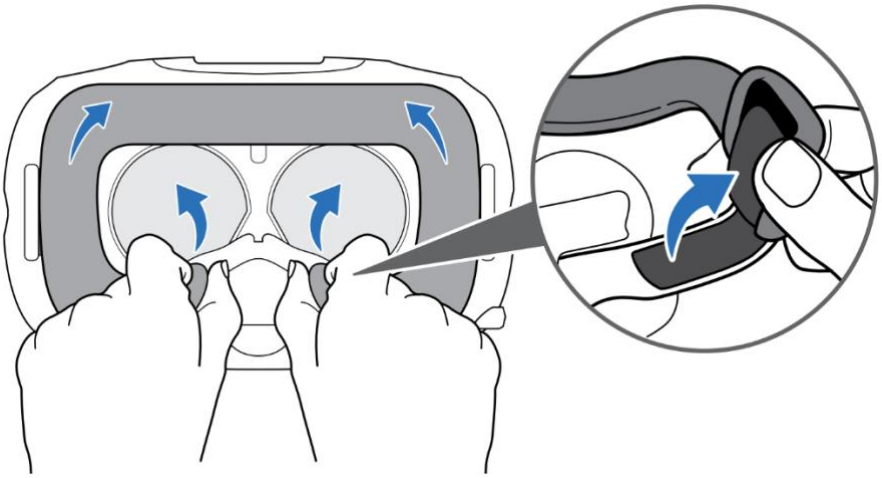


Figure A.5.

Cleaning the lenses

To clean the lenses of the headset, wipe the lenses with an alcohol soaked (or lens cleaner) microfiber cloth in a circular motion. Do not expose the lenses to direct sunlight as this may damage the display.

Figure A.6.

Status light

1. Green light shows the headset is active
2. Slowly blinking green, the headset is on standby
3. Red when an error has been encountered with the
4. cables or display

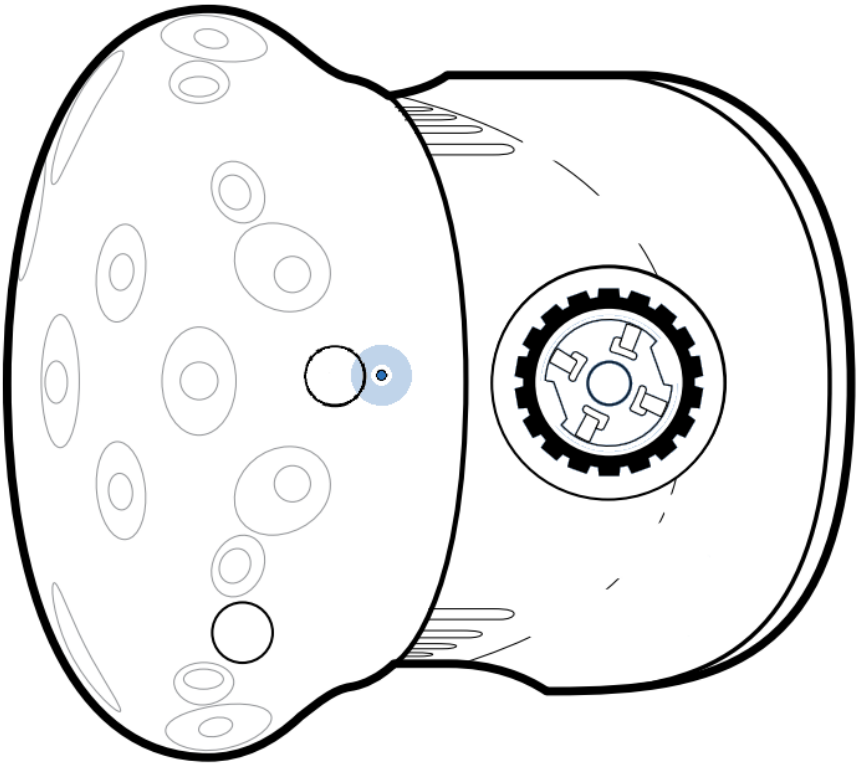


Figure A.7.

Link box

Connect the headset to the computer using the link box and provided cables. The headset is powered by a separate charger through the link box.

1. Headset cable
2. Power port
3. USB port
4. Mini DisplayPort (alternative to HDMI)
5. HDMI port

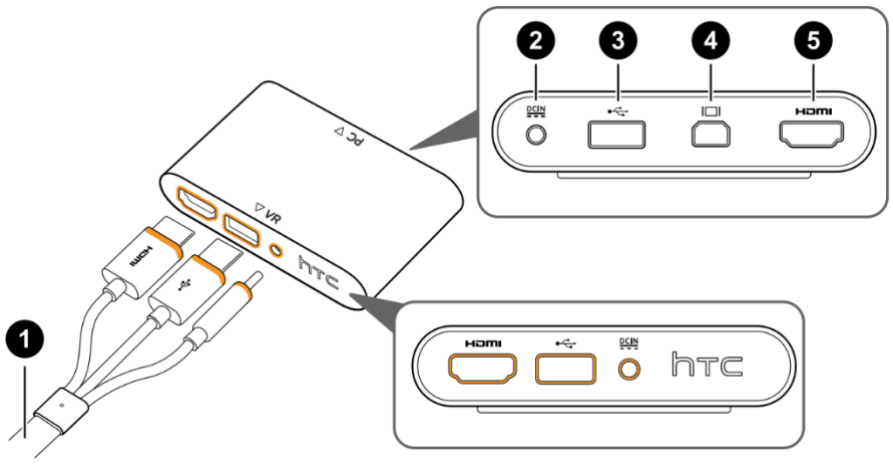


Figure A.8.

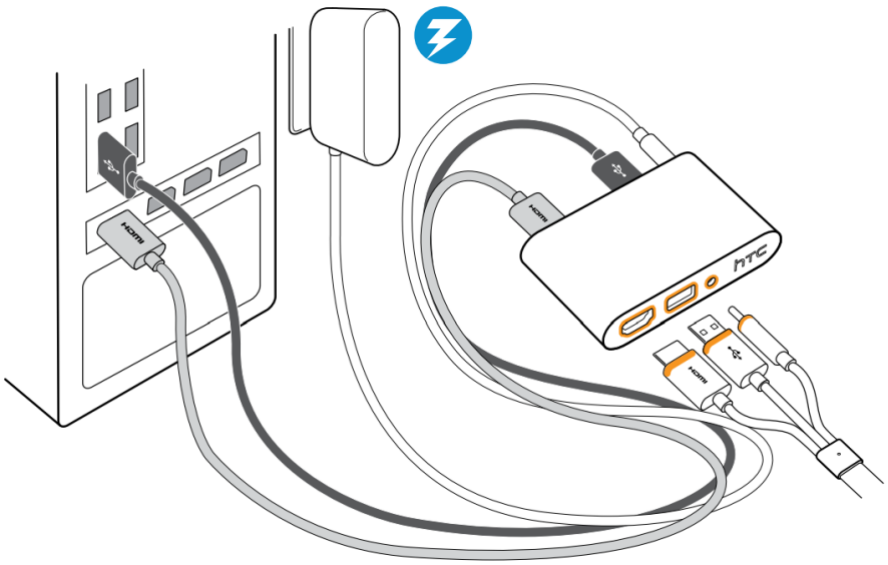


Figure A.9.

Setting up Steam VR

Before you can use Vive, you'll need to complete the setup process, which includes defining your play area. To begin, download and install the Steam app from http://store.steampowered.com/about/. You will need to create a Steam account. Once Steam is installed, or if you already have Steam, go to Library ⇒ Tools to install the SteamVR app. When done, the SteamVR app will launch.
In SteamVR select Run Room Setup ⇒ Room-scale and follow the on-screen instructions.