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МЕТОДИЧНІ ВКАЗІВКИ

**до практичних занять з англійської мови
для студентів І курсу
спеціальності 141 «Електроенергетика, електротехніка та електромеханіка» денної форми навчання**

«ELECTRIC MACHINES»

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Методичні вказівки до практичних занять з англійської мови для студентів I курсу спеціальності 141 «Електроенергетика, електротехніка та електромеханіка» денної форми навчання. «ELECTRIC MACHINES» /Укл. Ю. О. Соболь, В. Г. Кузьменко. – Запоріжжя: НУ «Запорізька політехніка», 2021. – 53 с.

Укладач: Ю. О. Соболь, В.Г. Кузьменко
Рецензент: П. Д. Андрієнко, доктор техн. наук, професор
Відповідальний за випуск: В. Г. Кузьменко

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CONTENTS

UNIT 1. BRUSHED DC ELECTRIC MOTOR

Text A

Before reading the text

Task 1. Match each phrase with the appropriate meaning.

1. brushed motor	a) викривлення (зміщення) поля
2. commutator brush	b) двигунвнутрішнього згорання
3. commutator plates	c) з реверсивною комутацією
4. commutating plane	d) пластини комутатора
5. reversible commutated	e) площина комутації
6. power output	f) ефект поля
7. field distortion	g) колекторна щітка
8. internal combustion engine	h) вихідна енергія
9. field effect	i) двигун з щітковим колектором

Task 2. Find synonym to each word or phrase in the list given below.

1. power source
2. turn
3. winding
4. rate
5. electromotive power
6. counter electromotive force
7. run
8. field coil

spin, electromotive force, coil, speed, wound field, back electromotive force, operate, source

Task 3. Find the words and phrases that have opposite meaning to:

1. rotor	a) outer
2. to result in …	b) movable
3. inner	c) advance
4. retard	d) stator
5. stationary	e) to result from

Task 4. Translate these phrases. Look carefully at the compound nouns before you start.

two pole DC motor; internally commutated electric motor; soft iron core; Fleming's left hand rule; two-pole design; zero-torque position; low-current battery-powered demonstration; free-spinning motor; excited magnets; severe commutator overheating.

Task 5. Try to explain why a brushed DC motor is so called.

Task 6.Read the text, translate it and check your answer.

A brushed DC motor is an internally commutated electric motor designed to be run from a DC power source.

The following graphics illustrate a two pole DC motor.

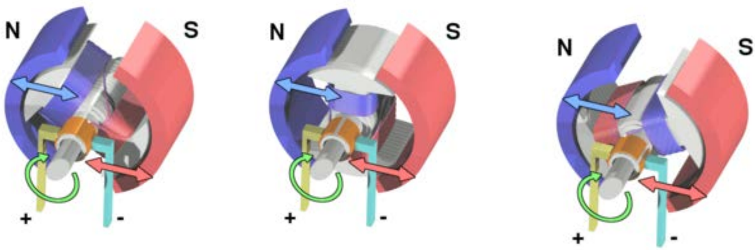

Figure 1.1— Simple Two Pole DC Motor Rotation

A simple DC electric motor. When the coil is powered, a magnetic field is generated around the armature. The left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation.

The armature continues to rotate.

When the armature becomes horizontally aligned, the commutator reverses the direction of current through the coil, reversing the magnetic field. The process then repeats.

When a current passes through the coil wound around a soft iron core, the side of the positive pole is acted upon by an upwards force, while the other side is acted upon by a downward force. According to Fleming's left hand rule, the forces cause a turning effect on the coil, making it rotate. To make the motor rotate in a constant direction, "direct current" commutators make the current reverse in direction every half a cycle thus causing the motor to rotate in the same direction.

The problem facing the motor shown above, is when the plane of the coil is parallel to the magnetic field; i.e. the torque is ZERO-when the rotor poles are displaced 90 degree from the stator poles. The motor would not be able to start in this position, but the coil can continue to rotate by inertia.

There is a secondary problem with this simple two-pole design; at the zero-torque position, both commutator brushes are touching across both commutator plates, resulting in a short-circuit that uselessly consumes power without producing any motion. In a low-current battery-powered demonstration this short-circuiting is generally not considered harmful, but if a two-pole motor were designed to do actual work with several hundred watts of power output, this shorting could result in severe commutator overheating, brush damage, and potential welding of the metallic brushes to the commutator.

Unlike the demonstration motor, above, DC motors are commonly designed with more than two poles, are able to start at any position, and do not have any position where current can flow without producing electromotive power.

If the shaft of a DC motor is turned by an external force, the motor will act like a generator and produce an Electromotive force (EMF). During normal operation, the spinning of the motor produces a voltage, known as the counter-EMF (CEMF) or back EMF, because it opposes the applied voltage on the motor. This is the same EMF that is produced when the motor is used as a generator (for example when an electrical load (resistance) is placed across the terminals of the motor and the motor shaft is driven with an external torque). Therefore, the voltage drop across a motor consists of the voltage drop, due to this CEMF, and the parasitic voltage drop resulting from the internal resistance of the armature's windings. The current through a motor is given by the following equation:

$$I = (V_{applied} - V_{cemf}) / R_{armature}$$

The mechanical power produced by the motor is given by:

$$P = I * (V_{cemf})$$

As an unloaded DC motor spins, it generates a backwards-flowing electromotive force that resists the current being applied to the motor. The current flow through the motor drops as the rotational speed increases, and a free-spinning motor has very little current flow. It is only when a load is applied to the motor that slows the rotor that the current flow through the motor increases. In an experiment of this kind made on a motor with separately excited magnets, the following figures were obtained:

Revolutions per minute	0	50	100	160	180	195
Amperes	20	16.2	12.2	7.8	6.1	5.1

Apparently, if the motor had been helped on to run at 261.5 revolutions per minute, the current would have been reduced to zero. In the last result obtained, the current of 5.1 amperes was absorbed in driving the armature against its own friction at the speed of 195 revolutions per minute.

In a DC motor, the contact point of where a pair of brushes touch the commutator is referred to as the *commutating plane*. In this diagram the commutating plane is shown for just one of the brushes.

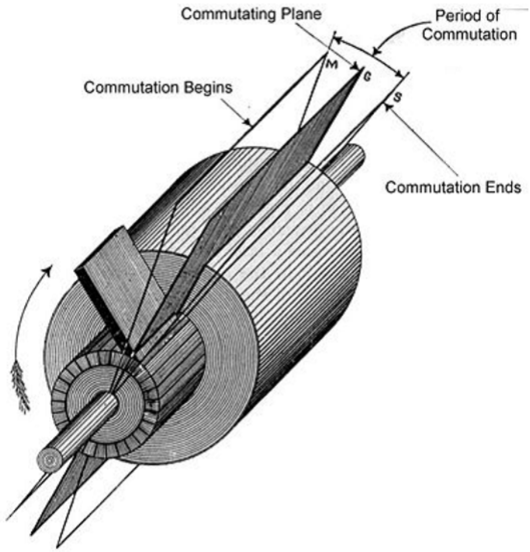

Figure 1.2 – Commutating plane for just one of the brushes

Vocabulary

motor–двигун
commutate–комутувати, перемикати
reverse–змінювати напрямок на зворотній
torque–обертаючий момент, пусковий момент
degree – градус, ступінь
inertia– інерція
generator–генератор
draw–витікати, протікати, живитись
excite– збуджувати(сь)

revolution– оберт

Task 7. Point out the sentences in the text in which the word “to make” should be translated as “примушувати”.

Task 8. Answer these questions about the text.

1. What is a brushed DC motor?
2. When is a magneticfield generated around thearmature?
3. What causes the rotation?
4. When does the commutator reverse the direction of current through the coil?
5. According to which rule is a turning effect caused on the coil?
6. What makes the motor rotate in a constant direction?
7. What will the motor produce if the shaft is turned by an external force?
8. What does the spinning of the motor produce during normal operation?

Task 9. Work in pairs. Ask your partner to answer these questions.

1. What does the voltage drop across a motor consists of?
2. What does an unloaded spinning DC motor generate?
3. When does the current flow through the motor increase?
4. What is referred to as the commutating plane?

Task 10. Find the sentences in the text telling you about two problems facing the simple two pole DC motor.

Text B

Compensation for stator field distortion

Before reading the text

Task 1. Match these words with the appropriate meaning.

1. dynamo	a) кут
2. compensation	b) розподіл (регулювання)

	моментів запалювання
3. uniform	c) перпендикулярний
4. angle	d) генератор постійного струму
5. normal	e) однорідний
6. timing	f) корекція, вирівнювання

Task 2. Try to explain what the phenomena of field distortion means.

Task 3. Read the text, translate it and check your answer.

In a real dynamo, the field is never perfectly uniform. Instead, as the rotor spins it induces field effects which drag and distort the magnetic lines of the outer non-rotating stator.

A B

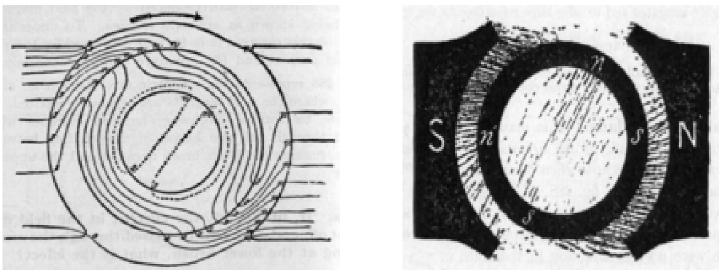

Figure 1.3 – Exaggerated example of how the field is distorted by the rotor (A). Iron filingss how the distorted field across the rotor (B)

The faster the rotor spins, the further the degree of field distortion. Because the dynamo operates most efficiently with the rotor field at right angles to the stator field, it is necessary to either retard or advance the brush position to put the rotor's field into the correct position to be at a right angle to the distorted field.

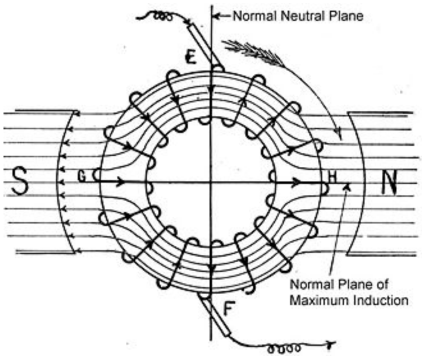

Figure 1.4 – Centered position of the commutating plane if there were no field distortion effects

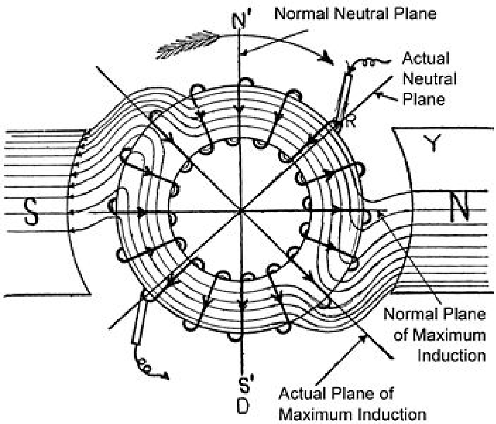

Figure 1.5 – Actual position of the commutating plane to compensate for field distortion

These field effects are reversed when the direction of spin is reversed. It is therefore difficult to build an efficient reversible commutated dynamo, since for highest field strength it is necessary to move the brushes to the opposite side of the normal neutral plane.

The effect can be considered to be somewhat similar to timing advance in an internal combustion engine. Generally a dynamo that has been designed to run at a certain fixed speed will have its brushes permanently fixed to align the field for highest efficiency at that speed.

Task 4. Answer these questions about the text.

1. Is the field perfectly uniform in the motor?
2. What distort the magnetic lines of the non-rotating stator?
3. What does the degree of field distortion depend on?
4. When does the motor operate most efficiently?
5. What is necessary to do to put the rotor field at a right angle to the distorted field?
6. When are the field effects reversed?

Task 5. Work in pairs. Ask your partner to answer the following questions.

1. Is it difficult to build an efficient reversible commutated dynamo? Why?
2. Why will a dynamo designed to run at a certain fixed speed have its brushes permanently fixed?

Text C

Dynamo design variations

Before reading the text

Task 1. Match each phrase in the left column with the appropriate meaning in the right column.

1. wound rotor	a) обмотка послідовного збудження
2. wound stator	b) магнітний ротор
3. series wound	c) фазний статор
4. shunt wound	d) обмотка паралельного збудження
5. rotor magnet	e) фазний ротор

Task 2. Translate these phrases. Look carefully at the compound nouns before you start.

permanent magnet motor; high-strength field; high-intensity permanent magnet; high-power motor.

Task 3. **Try to give some examples of the motor design.**

Task 4. **Read the text, translate it and check your answers.**

DC motors are commonly constructed with wound rotors and either wound or permanent magnet stators.

Wound stators. The field coils have traditionally existed in three basic formats: series wound, shunt wound, and a combination of the two.

Permanent Magnet Motors. Permanent magnet types have some performance advantages over wound stator types, and have become predominant in fractional horsepower applications. They can be smaller, lighter, more efficient and reliable.

Originally all large industrial DC motors used wound field or rotor magnets. Permanent magnets have traditionally only been useful on small motors because it was difficult to find a material capable of retaining a high-strength field. Only recently advances in materials technology have allowed the creation of high-intensity permanent magnets, such as neodymium magnets, allowing the development of compact, high-power motors without field coils.

Vocabulary

performance – продуктивність
horsepower – потужність в кінських силах
fractional – менше однієї кінської сили

Task 5. Answer these questions about the text.

1. How are DC motors commonly constructed?
2. What types of field coils are traditionally used?

3. What are the advantages of a permanent magnet type of DC motors?
4. What type of rotors was used originally in all large industrial motors?
5. What allowed the creation of high-intensity permanent magnets?

UNIT 2. 3-PHASE AC INDUCTION MOTOR

Text A

Before reading the text

Task 1. Match these phrases with the appropriate meaning.

1. induction motor	a) робочі (експлуатаційні) характеристики
2. variable speed drive	b) асинхронний двигун
3. variable voltage converter	c) привод з регульованою швидкістю
4. performance characteristics	d) перетворювач з регульованою напругою
5. single-phase	e) змінна (регульована) частота
6. variable frequency	f) однофазний

Task 2. Translate these phrases. Look carefully at the compound nouns before you start.

AC induction motor
slipring motor
squirrel cage induction motors
variable voltage variable frequency converter
automated manufacturing methods
computer based design optimization

Task 3. Find synonym to each word or phrase in the list given below.

1. mains
2. magnetic path
3. transfer
4. supply
5. power rating
6. adjustable

power supply, iron path, variable, rated power, power grid, transmit

Task 4. Make nouns by adding the appropriate suffix –er or –or to these verbs and translate them.

1. convert
2. compress
3. mix
4. process
5. agitate
6. crush
7. convey
8. rectify
9. break
10. amplify

Task 5. Try to explain the principal difference between DC and AC motors.

Task 6. Read the text, translate it and check your answer.

For industrial and mining applications, 3-phase AC induction motors are the prime movers for the vast majority of machines. These motors can be operated either directly from the mains or from adjustable frequency drives. In modern industrialized countries, more than half the total electrical energy used in those countries is converted to mechanical energy through AC induction motors. The applications for these motors cover almost every stage of manufacturing and processing. Applications also extend to commercial buildings and the domestic environment. They are used to drive pumps, fans, compressors, mixers, agitators, mills, conveyors, crushers, machine tools, cranes, etc. It is not surprising to find that this type of electric motor is so popular, when one considers its simplicity, reliability and low cost.

In the last decade, it has become increasingly common practice to use 3-phase squirrel cage AC induction motors with variable voltage variable frequency (VVVF) converters for variable speed drive (VSD) applications. To clearly understand how the VSD system works, it is necessary to understand the principles of operation of this type of motor.

Although the basic design of induction motors has not changed very much in the last 50 years, modern insulation materials, computer based design optimization techniques and automated manufacturing methods have resulted in motors of smaller physical size and lower cost per kW. International standardization of physical dimensions and frame sizes means that motors from most manufacturers are physically interchangeable and they have similar performance characteristics.

The reliability of squirrel cage AC induction motors, compared to DC motors, is high. The only parts of the squirrel cage motor that can wear are the bearings. Sliprings and brushes are not required for this type of construction. Improvements in modern pre-lubricated bearing design have extended the life of these motors.

Although single-phase AC induction motors are quite popular and common for low power applications up to approx. 2.2 kW, these are seldom used in industrial and mining applications. Single-phase motors are more often used for domestic applications.

The information in this chapter applies mainly to 3-phase squirrel cage AC induction motors, which is the type most commonly used with VVVF converters.

Vocabulary

adjust – регулювати
frequency – частота
drive – привод
machinetool – металорізальний станок
squirrelcage – біляча клітка
technique – метод
design – розробляти, конструювати, проектувати
automated – автоматизований
frame – рама, станина, корпус, конструкція
bearing – підшипник
slipring – контактне кільце

Task 7. Answer these questions about the text.

1. What kind of AC induction motors has become commonly used for variable speed drive applications?
2. Are sliprings and brushes required in the modern design of the squirrel cage motors?

Task 8. Decide whether the statement to the text is true or false. If you think a statement is false, change it to make it true.

3-phase AC induction motors are common for low power applications.

Task 9. Work in pairs. Ask your partner to give examples of AC induction motors application.

Task 10. Translate the sentences. Look carefully at the Indefinite Tenses in Active and Passive Voice before you start. Correct the mistakes in the sentences.

1. AC induction motors is used to drive mills, machine tools, compressors, conveyors, pumps, etc.
2. Their applications also extends to domestic environment.
3. To understand how the variable speed drive system work it is necessary to understand the principles of operation of this type of motor.
4. Single-phase AC induction motor are seldom used in industrial and mining applications.
5. International standardization means that motors from different manufacturers has similar performance characteristics.

Text B
Basic construction

Before reading the text

Task 1. Match each phrase in the list on the left with the appropriate meaning on the right.

1. laminated steel	a) вихровий струм
2. cast iron alloy	b) розподільна коробка (коробказовнішніх з’єднань)
3. aluminum alloy	c) шихтованасталь
4. eddy current	d) легований чавун
5. cross-section	e) легований алюміній
6. terminal box	f) поперечний розтин

Task 2. Translate these phrases from the text.

eddy current losses
frictional losses
windage losses
slotted steel laminations

Task 3. Look at the Fig. 55-56 and try to describe the construction of the AC induction motor.

Task 4. Read the text, translate it and check your answer.

The AC induction motor comprises 2 electromagnetic parts:

- stationary part called the stator;
- rotating part called the rotor, supported at each end on bearings.

The stator and the rotor are each made up of:

- an electric circuit, usually made of insulated copper or aluminum, to carry current;
- a magnetic circuit, usually made from laminated steel, to carry magnetic flux.

The stator. The stator is the outer stationary part of the motor, which consists of:

- the outer cylindrical frame of the motor, which is made either of welded sheet steel, cast iron or cast aluminum alloy. This may include feet or a flange for mounting;
- the magnetic path, which comprises a set of slotted steel laminations pressed into the cylindrical space inside the outer frame. The magnetic path is laminated to reduce eddy currents, lower losses and lower heating;
- a set of insulated electrical windings, which are placed inside the slots of the laminated magnetic path. The cross-sectional area of these windings must be large enough for the power rating of the motor. For a 3-phase motor, 3 sets of windings are required, one for each phase.

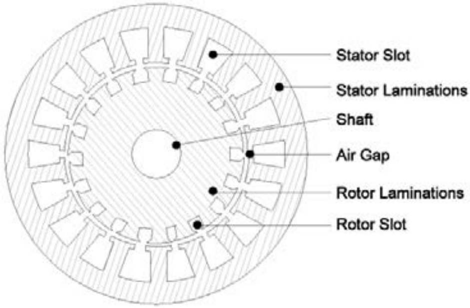

Figure 2.1 – Stator and rotor laminations

The rotor. This is the rotating part of the motor. As with the stator above, the rotor consists of a set of slotted steel laminations pressed together in the form of a cylindrical magnetic path and the electrical circuit. The electrical circuit of the rotor can be either:

- wound rotor type, which comprises 3 sets of insulated windings with connections brought out to 3 sliprings mounted on the shaft. The external connections to the rotating part are made via brushes onto the sliprings. Consequently, this type of motor is often referred to as a slipring motor;
- squirrel cage rotor type, which comprises a set of copper or aluminum bars installed into the slots, which are connected to an end-ring at each end of the rotor. The construction of these rotor windings resembles a ‘squirrel cage’. Aluminum rotor bars are usually die-cast into the rotor slots, which results in a very rugged construction. Even though the aluminum rotor bars are in direct contact with the steel laminations, practically all the rotor current flows through the aluminum bars and not in the laminations.

The other parts. The other parts, which are required to complete the induction motor are:

- two end-flanges to support the two bearings, one at the drive-end (DE) and the other at the nondrive-end (NDE);
- two bearings to support the rotating shaft, at DE and NDE;
- steel shaft for transmitting the torque to the load;
- cooling fan located at the NDE to provide forced cooling for the stator and rotor;

- terminal box on top or either side to receive the external electrical connections.

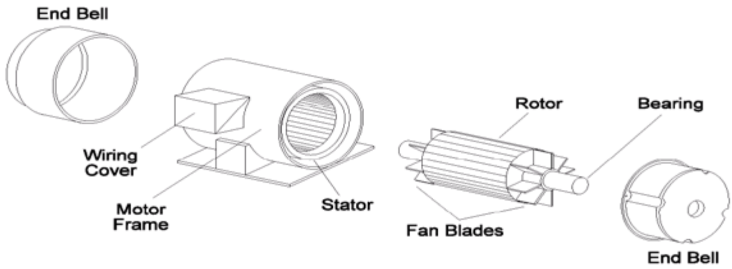

Figure 2.2 – Assembly details of a typical AC induction motor

Vocabulary

carry – проводити
welded – зварний
mount – монтувати
slot – проріз, паз
losses – втрати
bar – шина
install – установлювати
die-cast – литий
rugged – жорсткий
support – основа, опора, підтримувати
forced – примусовий

Task 5. Answer these questions about the text.

1. What types of electrical circuit can have the rotor?
2. What does the wound rotor comprise?
3. What does the squirrel cage rotor comprise?
4. The AC induction motor comprises two electromagnetic parts: stator and rotor. What other parts are required to complete it?
5. Where does the steel shaft transmit the torque?
6. What kind of cooling does the fan provide for the stator and rotor?

Task 6. Decide whether the statements to the text are true or false. If you think a statement is false, change it to make it true.

1. Two bearings support two end-flanges.
2. Cooling fan is located at the drive-end.
3. The rotating shaft is supported by two bearings.

Task 7. Translate the sentences. Look carefully at the Indefinite Tenses in Active and Passive before you start. Correct the mistakes in the sentences.

1. Current flow through the copper or aluminum bars and not in the laminations.
2. Slots is connected to an end-ring at each end of the rotor.
3. Rotor bars is in direct contact with the steel laminations.
4. Wound rotor type of motor are often referred to as a slipring motor.
5. To receive the external electrical connections there are a terminal box on the top on either side of the frame.

Text C

Principles of operation

Before reading the text

Task 1. Match each phrase with the appropriate meaning.

<u>**A**</u>

1. synchronous speed	a) номінальна швидкість (розрахована швидкість)
2. actual speed	b) швидкість ковзання
3. slip speed	c) дійсна швидкість
4. rated speed	d) синхронна швидкість

B

1.	load torque	a)	пусковий момент
2.	starting torque	b)	гальмовий момент
3.	output torque	c)	обертаючий момент при навантаженні
4.	breakaway torque	d)	вихідний обертовий момент

C

1.	short circuited	a)	послідовність фаз
2.	rotational force	b)	напруга живлення
3.	phase sequence	c)	закорочений, коротко замкнутий
4.	supply voltage	d)	обертаюча сила

Task 2. Look at the Figures2.3, 2.4 and try to explain the principle of operation of the AC induction motor.

Task 3.Read the text, translate it and check your answer.

When a 3-phase AC power supply is connected to the stator terminals of an induction motor, 3-phase alternating current flows in the stator windings. These currents set up a changing magnetic field (flux pattern), which rotates around the inside of the stator. The speed of rotation is in synchronism with the electric power frequency and is called the synchronous speed.

In the simplest type of 3-phase induction motor, the rotating field is produced by 3 fixed stator windings, spaced 120^0 apart around the perimeter of the stator. When the three stator windings are connected to the 3-phases power supply, the flux completes one rotation for every cycle of the supply voltage. On a 50Hz power supply, the stator flux rotates at a speed of 50 revolutions per second, or 50 x 60 = 3000 rev per minute.

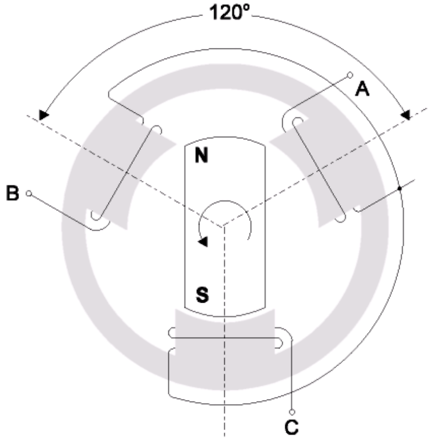

Figure 2.3 -Basic (simplified) principle of a 2 pole motor

A motor with only one set of stator electrical windings per phase, as described above, is called a 2 pole motor (2p) because the rotating magnetic field comprises 2 rotating poles, one North-pole and one South-pole. In some countries, motors with 2 rotating poles are also sometimes called a 1 pole-pair motor.

If there were a permanent magnet inside the rotor, it would follow in synchronism with the rotating magnetic field. The rotor magnetic field interacts with the rotating stator flux to produce a rotational force. A permanent magnet is only being mentioned because the principle of operation is easy to understand. The magnetic field in a normal induction motor is induced across the rotor air-gap as described below.

If the three windings of the stator were re-arranged to fit into half of the stator slots, there would be space for another 3 windings in the other half of the stator. The resulting rotating magnetic field would then have 4 poles (two North and two South), called a 4 pole motor. Since the rotating field only passes 3 stator windings for each power supply cycle, it will rotate at half the speed of the above example, 1500 rev/min.

Consequently, induction motors can be designed and manufactured with the number of stator windings to suit the base speed required for different applications:

- 2 pole motors, stator flux rotates at 3000 rev/min

- 4 pole motors, stator flux rotates at 1500 rev/min
- 6 pole motors, stator flux rotates at 1000 rev/min
- 8 pole motors, stator flux rotates at 750 rev/min
- etc.

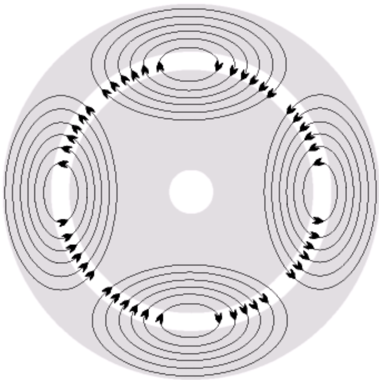

Figure 2.4 -Flux distribution in a 4 pole machine at any one moment

The speed at which the stator flux rotates is called the synchronous speed and, as shown above, depends on the number of poles of the motor and the power supply frequency.

$$n_o = \frac{f \times 60}{pole - pairs} = \frac{f \times 60}{p/2} \quad \text{rev/min}$$

$$n_o = \frac{f \times 120}{p} \quad \text{rev/min}$$

Where: n_o = synchronous rotational speed in rev/min
f = power supply frequency in Hz
p = number of motor poles

To establish a current flow in the rotor, there must first be a voltage present across the rotor bars. This voltage is supplied by the magnetic field created by the stator current. The rotating stator magnetic flux, which rotates at synchronous speed, passes from the stator iron path, across the air-gap between the stator and rotor and penetrates the rotor iron path as shown in Figure 2.4. As the magnetic field rotates, the lines of flux cut across the rotor conductors. In accordance with Faraday's Law, this induces a voltage in the rotor windings, which is dependent on the rate of change of flux.

Since the rotor bars are short circuited by the end-rings, current flowing in these bars will set up its own magnetic field. This field interacts with the rotating stator flux to produce the rotational force. In accordance with Lenz's Law, the direction of the force is that which tends to reduce the changes in flux field, which means that the rotor will accelerate to follow the direction of the rotating flux.

At starting, while the rotor is stationary, the magnetic flux cuts the rotor at synchronous speed and induces the highest rotor voltage and, consequently, the highest rotor current. Once the rotor starts to accelerate in the direction of the rotating field, the rate at which the magnetic flux cuts the rotor windings reduces and the induced rotor voltage decreases proportionately. The frequency of the rotor voltage and current also reduces.

When the speed of the rotor approaches synchronous speed at no load, both the magnitude and frequency of the rotor voltage becomes small. If the rotor reached synchronous speed, the rotor windings would be moving at the same speed as the rotating flux, and the induced voltage (and current) in the rotor would be zero. Without rotor current, there would be no rotor field and consequently no rotor torque. To produce torque, the rotor must rotate at a speed slower (or faster) than the synchronous speed.

Consequently, the rotor settles at a speed slightly less than the rotating flux, which provides enough torque to overcome bearing friction and windage. The actual speed of the rotor is called the slip speed and the difference in speed is called the slip. Consequently, induction motors are often referred to as asynchronous motors because the rotor speed is not quite in synchronism with the rotating stator flux. The amount of slip is determined by the load torque, which is the torque required to turn the rotor shaft.

For example, in a 4 pole motor, with the rotor running at 1490 r/min on no-load, the rotor frequency is 10/1500 of 50 Hz and the induced voltage is approximately 10/1500 of its value at starting. At no-load, the rotor torque associated with this voltage is required to overcome the frictional and windage losses of the motor.

As shaft load torque increases, the slip increases and more flux lines cut the rotor windings, which in turn increases rotor current, which increases the rotor magnetic field and consequently the rotor torque. Typically, the slip varies between about 1% of synchronous speed at no-load to about 6% of synchronous speed at full-load.

$$Slip = s = \frac{(n_0 - n)}{n_0} \; per\ unit \quad 1$$

and actual rotational speed is

$$n = n_0(1 - s) \quad rev/min \quad 2$$

Where n_o = synchronous rotational speed in rev/min
n = actual rotational speed in rev/min
s = slip in per-unit

The direction of the rotating stator flux depends on the phase sequence of the power supply connected to the stator windings. The phase sequence is the sequence in which the voltage in the 3-phases rises and reaches a peak. Usually the phase sequence is designated A-B-C, L1-L2-L3 or R-W-B (Red-White-Blue). In Europe this is often designated as U-V-W and many IEC style motors use this terminal designation. If two supply connections are changed, the phase sequence A-C-B would result in a reversal of the direction of the rotating stator flux and the direction of the rotor.

Vocabulary

air-gap – повітряний зазор
windage – опір повітря
amount – величина, ступінь, міра
no-load – без навантаження
peak – пік, максимум
requirement – необхідна умова, вимога
pullaway – відриватись, розганятись

Task4. Answer these questions about the text.

1. What currents set up a changing magnetic field which rotates around the inside of the stator?

2. What is a synchronous speed?
3. What is the rotating field produced by in the simplest type of 3-phase induction motor?
4. How many rotations for every cycle of the supply voltage does the flux perform when the three stator windings are connected to the 3-phase power supply?
5. What is a 2 pole motor?
6. Where is a magnetic field induced in a normal induction motor?
7. What must be present across the rotor bars to establish a current flow in the rotor?
8. What speed must the rotor rotate at to produce torque?

Task 5. Work in pairs. Ask your partner these questions and let him answer them.

1. What is a slip?
2. What is a slip speed?
3. What is the amount of slip determined by?
4. What does the direction of the rotating stator flux depend on?
5. What is a phase sequence?

Task 6. Decide the functions of Participle I and Participle II in these sentences.

1. When the induction motor is supplied from a power source of constant voltage and frequency, the current drawn by the motor depends primarily on the slip.
2. At no-load, the motor will draw only no-load magnetizing current.
3. When matching motors to mechanical loads, the two most important considerations are torque and speed.
4. Induced voltage reappears in the rotor, but in the opposite direction.
5. When set up a changing magnetic field rotates around the inside of the stator.

Task 7. Decide which of the sentences are in the Active and which are in the Passive Voice.

1. In contrast with a DC motor, the AC induction motor doesn't have separate field windings.
2. The performance of the 3-phase AC induction motor has been described for the speed range from zero up to its rated speed at 50 Hz.
3. Typically, the slip varies between about 1% of synchronous speed at no-load to about 6% of synchronous speed at full-load.
4. The induction motor will always run at a speed lower than synchronous speed because, even at no-load, a small slip is required to ensure that there is sufficient torque to overcome friction and windage losses.
5. Inertia can be calculated using the formula.

Task 8. Match the sentences halves to form complete sentences. Look carefully at the first conditional sentences before you start.

1.	If the motor torque always exceeds the load torque,	a)	the induced voltage and current in the rotor fell to zero.
2.	If the load torque increases,	b)	the rotor was running faster than the rotating stator field.
3.	If the rotor speed was increased to the point that there was no slip,	c)	the motor speed drops slightly.
4.	If the rotor speed was increased above the mentioned one,	d)	the motor will stall.
5.	When the motor torque is less than the load torque,	e)	the motor accelerates.

Task 9. Complete the second conditional sentences with the words below.

1. If there … a permanent magnet inside the rotor, it … in synchronism with the rotating magnetic field.

2. If the three windings of the stator … to fit into half of the stator slots, there … space for another 3 windings in the other half of the stator.

3. If the rotor … synchronous speed, the rotor windings … at the same speed as the rotating flux, and the induced voltage (and current) in the rotor would be zero.

4. If two supply connections … , the phase sequence A-C-B … in a reversal of the direction of the rotating stator flux and the direction of the rotor.

5. If the load torque … to a point beyond T_{max}, the motor … .

6. If the acceleration torque … over the acceleration period the formula of the total acceleration time … .

a) increased, would stall
b) reached, would be moving
c) were constant, would simplify
d) were changed, would result
e) were, would follow
f) were re-arranged, would be

TEST (Unit 1. Brushed DC electric motor. Unit 2. 3-phase AC induction motor)

Choose the correct answer

1. Which of the following makes the coil rotate?

A. Fleming's left hand rule

B. Kirchhoff 's law
C. Ohm's law
D. Magnetic field

2. Which of the following is not a counter electromotive force?

A. Back EMF
B. Counter EMF
C. Two pole DC motor
D. Backward flowing electromotive force

3. When a DC motor is unloaded, what does the CEMF do?
A. Increases current flow
B. Resists the current applied to the motor
C. Decreases the speed of motor rotation
D. Stops the motor

4. Which of the motors is used to convert electrical energy into mechanical one

A. DC motor
B. AC induction motor
C. Squirrel cage
D. Single-phase motor

5. What are the only parts of the squirrel cage motor that can wear?

A. Sliprings
B. Brushes
C. Bearings
D. Coils

6. Why is a wound rotor type motor often called a slipring motor?

A. Steel laminations are pressed together

B. External connections are made via brushes onto the sliprings
C. Aluminum bars are in contact with laminations
D. Flanges support bearings

7. Why is squirrel cage rotor type motor so called?

A. Bearings support the shaft
B. Construction of rotor windings resembles a “squirrel cage”
C. Shaft transmits the torque to the load
D. Fan provides cooling for the rotor

8. When magnetic field rotates, the lines of flux cut across the rotor conductors. According to which law a voltage is induced in the rotor windings?

A. Kirchhoff ’s law
B. Lenz’s law
C. Ohm’s law
D. Faraday’s law

9. Current flowing in the rotor bars sets up its own magnetic field which interacts with the rotating stator flux and produces the rotational force. According to which law the direction of this force tends to reduce the changes in the flux field?
A. Faraday’s law
B. Lenz’s law
C. Kirchhoff ’s law
D. Ohm’s law

10. At starting, when the rotor is stationary, the magnetic flux cuts the rotor at synchronous speed. What voltage and current does it induce?
A. Low
B. High
C. The lowest
D. The highest

UNIT3. TRANSFORMER

Text A

Before reading the text

Task 1. Match each phrase in the left column with the appropriate meaning in the right column.

A

1. magnetic coupling	a) коефіцієнт трансформації по напрузі
2. mutual inductance	b) активне навантаження
3. primary winding	c) середньоквадратичний
4. secondary winding	d) взаємоіндукція
5. turns ratio	e) первинна обмотка
6. voltage ratio	f) вторинна обмотка
7. flux density	g) магнітна взаємодія
8. resistive load	h) коефіцієнт трансформації
9. root mean square	i) густота потоку

B

1. coupling transformer	a) розв'язуючий трансформатор
2. step-up transformer	b) вимірювальний трансформатор
3. step-down transformer	c) підвищуючий трансформатор
4. isolating transformer	d) трансформатор зв'язку
5. variable transformer	e) знижуючий трансформатор
6. instrument transformer	f) регулюючий трансформатор

Task 2. Find the meaning of these adverbs in the list given below.

1. proportionally
2. respectively
3. alternately
4. inversely
5. mutually
6. gradually
7. hypothetically

взаємно, відповідно, гіпотетично, обернено, поступово, пропорційно, інакше

Task 3.Translate these phrases from the text.

time-varying magnetic flux; thumbnail-sized coupling transformer; inversely proportional; magnetic flux density; peak magnetic flux density.

Task 4. Look at Fig. 59 and try to describe the transformer construction.

Task 5. Read the text, translate it and check your answer.

A *transformer* is an electrical device that transfers energy from one circuit to another by magnetic coupling, without requiring relative motion between its parts. A transformer comprises two or more coupled windings, and, in most cases, a magnetic core to concentrate magnetic flux. A changing voltage applied to one winding creates a time-varying magnetic flux in the core, which induces a voltage in the other windings.

The transformer is one of the simplest of electrical devices, yet transformer designs and materials continue to be improved.

Transformers come in a range of sizes from a thumbnail-sized coupling transformer hidden inside a stage microphone to huge gigawatt units used to interconnect large portions of national power grids. All operate with the same basic principles and with many similarities in their parts.

Michael Faraday built the first transformer in 1831, although he used it only to demonstrate the principle of electromagnetic induction and did not foresee its practical uses.

Coupling by mutual induction. The principles of the transformer are illustrated by consideration of a hypothetical ideal transformer. In this case, the core requires negligible magnemotive force to sustain flux, and all flux linking the primary winding also links the secondary winding. The hypothetical ideal transformer has no resistance in its coils. A simple transformer consists of two electrical conductors called the *primary winding* and the *secondary winding*. Energy is coupled between the windings by the time varying magnetic flux that passes through (links) both primary and secondary windings. Whenever the amount of current in a coil changes, a voltage is induced in the neighboring coil. The effect, called mutual inductance, is an example of electromagnetic induction.

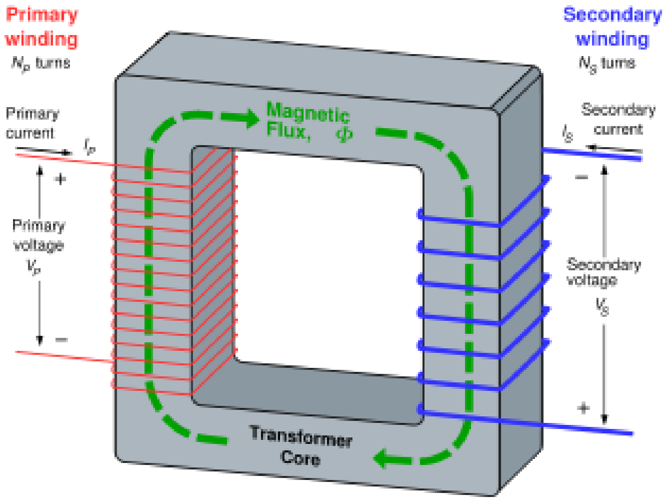

Figure 3.1 –An ideal step-down transformer showing flux in the core

If a time-varying voltage v_P is applied to the primary winding of N_P turns, a current will flow in it producing a magnetomotive force (MMF). Just as an electromotive force (EMF) drives current around an electric circuit, so MMF tries to drive magnetic flux through a magnetic circuit. The primary MMF produces a varying magnetic flux Φ_P in the core, and, with an open circuit secondary winding, induces a back electromotive force (EMF) in opposition to v_P. In accordance with Faraday's law of induction, the voltage induced across the primary winding is proportional to the rate of change of flux:

$$v_P = N_P \frac{d\Phi_P}{dt} \quad \text{and} \quad v_S = N_S \frac{d\Phi_S}{dt}$$

where

– v_P and v_S are the voltages across the primary winding and secondary winding,

– N_P and N_S are the numbers of turns in the primary winding and secondary winding,

$d\Phi_P / dt$ and $d\Phi_S / dt$ are the derivatives of the flux with respect to time of the primary and secondary windings.

In the hypothetical ideal transformer, the primary and secondary windings are perfectly coupled, or equivalently, $\Phi_P = \Phi_S$. Substituting and solving for the voltages shows that:

$$\frac{v_P}{v_S} = \frac{N_P}{N_S}$$

where

– v_p and v_s are voltages across primary and secondary,

– N_p and N_s are the numbers of turns in the primary and secondary, respectively.

Hence in an ideal transformer, the ratio of the primary and secondary voltages is equal to the ratio of the number of turns in their windings, or alternatively, the voltage per turn is the same for both windings. The ratio of the currents in the primary and secondary circuits is inversely proportional to the turns ratio.

The EMF in the secondary winding will cause current to flow in a secondary circuit. The MMF produced by current in the secondary winding opposes the MMF of the primary winding and so tends to cancel the flux in the core. Since the reduced flux reduces the EMF induced in the primary winding, increased current flows in the primary circuit. The resulting increase in MMF due to the primary current offsets the effect of the opposing secondary MMF. In this way, the electrical energy fed into the primary winding is delivered to the secondary winding. In addition, the flux density will always stay the same as long as the primary voltage is steady.

For example, suppose a power of 50 watts is supplied to a resistive load from a transformer with a turns ratio of 25:2.

– P = EI (power = electromotive force × current)

50 W = 2 V × 25 A in the primary circuit if the load is a resistive load.

– Now with transformer change:

50 W = 25 V × 2 A in the secondary circuit.

Since a direct current by definition does not change, it produces a steady MMF and so steady flux in the core; this quantity does not change and so cannot induce a voltage in the secondary winding. In a practical transformer, direct current applied to the winding will create only heat.

Vocabulary

transformer – трансформатор
coupling – зв’язок, взаємодія
unit – пристрій, апарат, установка
interconnection – міжз’єднання
derivative – похідна
derivative … with respect to …– похідна ... по ...
ratio – відношення, співвідношення, коефіцієнт
flux density – густота потоку

Task 6. Answer these questions about the text.

1. What is a transformer?
2. What does a transformer comprise?
3. What does a changing voltage applied to one winding create in the core?
4. What does a time-varying magnetic flux induce in the other windings?
5. What sizes do transformers have?
6. What magneto-motive force does the core require to sustain a magnetic flux in an ideal transformer?
7. What does a magnetic flux linking the primary winding do?
8. Has the ideal transformer resistance in its coils?
9. What is mutual induction?
10. What will current produce in the primary winding if a time-varying voltage is applied to it?
11. What produces a back electromotive force?
12. What does Faraday’s law of induction state?
13. What is the ratio of the primary and secondary voltages equal to?
14. What is inversely proportional to the turns ratio?
15. What will the EMF in the secondary winding cause?
16. What is produced by current in the secondary winding?

Task7. Work in pairs. Ask your partner to answer these questions and let him answer them.

1. What tends to cancel the flux in the core ?
2. How the electrical energy fed into the primary winding is delivered to the secondary winding?
3. How long will the flux density stay the same?
4. What kind of current produces a steady MMF and so steady flux in the core?
5. Can steady MMF induce a voltage in the secondary winding?
6. What relationship is given by the universal emf equation?

Text B
Operation at different frequencies

Before reading the text

Task 1. Match each word and phrase in the list on the left with the appropriate meaning on the right.

1. skin-effect	a) частота вища номінальної
2. circuit isolation	b) розрахована напруга
3. power frequency	c) захист від перезбудження
4. impedance matching	d) розв'язка кола
5. designed voltage	e) відношення напруги до частоти
6. "volts per hertz"	f) поверхневий ефект, скін-ефект
7. over-excitation protection	g) узгодження повного опору
8. higher-than-rated frequency	h) частота мережі

Task 2.Try to remember the types of transformers.

Task 3.Read the text, translate it and check your answer.

The equation shows that the EMF of a transformer at a given flux density increases with frequency. For operation at higher frequencies, transformers can be physically more compact without reaching saturation, and a given core is able to transfer more power. However, other properties of the transformer, such as losses within the core and skin-effect, also increase with frequency. Generally, operation of a transformer at its designed voltage but at a higher frequency than intended will lead to reduced magnetising (no load primary) current. At a frequency lower than the design value, with the rated voltage applied, the magnetising current may increase to an excessive level.

Operation of a power transformer at other than its designed frequency may require assessment of voltages, losses, and cooling to establish if safe operation is practical. For example, transformers at hydroelectric generating stations may be equipped with over-excitation protection, so-called "volts per hertz" protection relays, to protect the transformer from overvoltage at higher-than-rated frequency which may occur if a generator loses its connected load.

Classifications. Transformers are adapted to numerous engineering applications and may be classified in many ways:

– by power level (from fraction of a volt-ampere(VA) to over a thousand MVA);
– by application (power supply, impedance matching, circuit isolation);
– by frequency range (power, audio, radio frequency(RF));
– by voltage class (a few volts to about 750 kilovolts);
– by cooling type (air cooled, oil filled, fan cooled, water cooled, etc.);
– by purpose (distribution, rectifier, arc furnace, amplifier output, etc.).

By ratio of the number of turns in the coils transformers are classified:

Step-up. The secondary has more turns than the primary.

Step-down. The secondary has fewer turns than the primary.

Isolating.Intended to transform from one voltage to the same voltage. The two coils have approximately equal numbers of turns, although often there is a slight difference in the number of turns, in order to compensate for losses (otherwise the output voltage would be a little less than, rather than the same as, the input voltage).

Variable. The primary and secondary have an adjustable number of turns, which can be selected without reconnecting the transformer.

Vocabulary

property – властивість
relay – реле
overvoltage – перенапруга
overexcitation – перезбудження

Task 4. Work in pairs.

1. Ask your partner to give the classification of transformers according to engineering applications.
2. Let your partner tell about the classification of the transformers by ratio of the number of turns in the coils.

Text C

Limitations

Before reading the text

Task 1. Match these phrases with their appropriate meaning.

1.	iron losses	a)	втрати в обмотці
2.	energy losses	b)	паразитні втрати
3.	winding resistance losses	c)	втрати на охолоджувальну систему
4.	eddy current losses	d)	втрати на магнітострикцію
5.	hysteresis losses	e)	втрати на механічні процеси
6.	magnetostriction losses	f)	втрати на вихрові струми
7.	mechanical losses	g)	втрати на гістерезис
8.	stray losses	h)	втрати енергії
9.	cooling system losses	i)	активнівтрати
10.	copper losses	j)	втрати у сердечнику

Task 2. Translate these phrases from the text.

highly efficient; resistive heating; large power transformers; frictional heating; alternating magnetic field; fluctuating electromagnetic forces; transformer support structure; water-cooled heat exchanger; load-dependent losses; no-load losses.

Task 3. Try to explain all functions that transformer performs.

Task 4. Read the text, translate it and check your answer.

Transformers alone cannot do the following:

– Convert DC to AC or vice versa
– Change the voltage or current of DC
– Change the AC supply frequency.

However, transformers are components of the systems that perform all these functions.

Energy losses. An ideal transformer would have no losses, and would therefore be 100% efficient. In practice, energy is dissipated due both to the resistance of the windings known as *copper loss* or I^2R loss, and to magnetic effects primarily attributable to the core (known as *iron loss*). Transformers are, in general, highly efficient: large power transformers (over 50 MVA) may attain an efficiency as high as 99.75%. Small transformers, such as a plug-in "power brick" used to power small consumer electronics, may be less than 85% efficient.

Transformer losses:

– **Winding resistance.** Current flowing through the windings causes resistive heating of the conductors (I^2 R loss). At higher frequencies, skin effect and proximity effect create additional winding resistance and losses.

– **Eddy currents.** Induced eddy currents circulate within the core, causing resistive heating. Silicon is added to the steel to help in controlling eddy currents. Adding silicon also has the advantage of stopping aging of the electrical steel that was a problem years ago.

– **Hysteresis losses.** Each time the magnetic field is reversed, a small amount of energy is lost to hysteresis within the magnetic core. The amount of hysteresis is a function of the particular core material.

– **Magnetostriction.** Magnetic flux in the core causes it to physically expand and contract slightly with the alternating magnetic field (producing a buzzing sound), an effect known as magnetostriction. This in turn causes losses due to frictional heating in susceptible ferromagnetic cores.

– **Mechanical losses.** In addition to magnetostriction, the alternating magnetic field causes fluctuating electromagnetic forces between the primary and secondary windings. These incite vibrations within nearby metalwork, creating a familiar humming or buzzing noise, and consuming a small amount of power.

– **Stray losses.** Not all the magnetic field produced by the primary is intercepted by the secondary. A portion of the leakage flux may induce eddy currents within nearby conductive objects, such as the transformer support structure, and be converted to heat.

– **Cooling system.** Large power transformers may be equipped with cooling fans, oil pumps or water-cooled heat exchangers designed to remove the heat caused by copper and iron losses. The power used to operate the cooling system is typically considered part of the losses of the transformer.

Losses may be either load-dependent ('load-losses') or independent of it ('no-load loss'). Winding resistance dominates load-losses, whereas hysteresis and eddy currents losses contribute to over 99% of the no-load loss.

Vocabulary

dissipate – розсіюватись
plug-in – вставний
power brick – блок живлення
proximity effect – вплив близкості зворотного (сусіднього) провода
magnetostriction – магнітострикція
expand – розширювати(ся)
contract – взаємодіяти
incite – збуджувати
vibration – коливання
intercept – перехоплювати
leakage flux – потік розсіювання
support structure – несуча конструкція

dominate – впливати
contribute – сприяти

Task 5. Answer these questions about the text.

1. What cannot transformers do alone?
2. What kinds of losses are attributable to transformers?

Task 6. Decide whether these statements are true or false. If you think a statement is false, change it to make it true.

1. Fluctuating electromagnetic forces between the primary and secondary windings doesn't incite vibrations within nearby metalwork.
2. Small power transformers may be equipped with cooling fans, oil pumps or water-cooled heat exchangers.

Task 7. Work in pairs. Discuss all kinds of losses with your partner.

Text D

Cores

Before reading the text

Task 1. Match each phrase in the left column with the appropriate meaning in the right column.

1. inrush current	a) робоча частота
2. overcurrent protection	b) пробійний струм
3. power transmission line	c) діапазон високих частот
4. false operation	d) захист від надструмів
5. operating frequency	e) лінія електропередачі
6. high frequency band	f) помилкове спрацьовування

Task 2. Translate these phrases from the text.

typical laminated core; E-shaped and I-shaped pieces; triangular cross-section; static magnetic field; remanent magnetism; overcurrent protection device; power transmission line; long overhead power transmission line; transformer protection device; very high frequency band; effective gap width.

Task 3. Try to answer if the shape of the core and the material it is made of affect the transformer properties.

Task 4. Read the text, translate it and check your answer.

A typical laminated core is made from E-shaped and I-shaped pieces, leading to the name "EI transformer". In the EI transformer, the laminations are stacked in what is known as an interleaved fashion. Due to this interleaving a second gap in parallel (in an analogy to electronic circuits) to the gap between E and I is formed between the E-pieces. The E-pieces are pressed together to reduce the gap width to that of the insulation. The gap area is very large, so that the effective gap width is very small (in analogy to a capacitor). For this to work the flux has to gradually flow from one E to the other. That means that on one end all flux is only on every second E. That means saturation occurs at half the flux density. Using a longer E and wedging it with two small Is will increase the overlap and additionally make the grains more parallel to the flux (think of a wooden frame for a window). If an air gap is needed (which is unlikely considering the low remanence available for steel), all the Es are stacked on one side, and all the Is on the other creating a gap.

The cut core or C-core is made by winding a silicon steel strip around a rectangular form. After the required thickness is achieved, it is removed from the form and the laminations are bonded together. It is then cut in two forming two C shapes. The faces of the cuts are then ground smooth so they fit very tight with a very small gap to reduce losses. The core is then assembled by placing the two C halves together, and holding them closed by a steel strap. Usually two C-cores are used to shorten the return path for the magnetic flux resulting in a form similar to the EI. More cores would necessitate a triangular cross-section. Like toroidal cores, they have the advantage, that the flux is always in the oriented parallel grains. Due to the bending of the core, some area is lost for a rectangular winding.

A steel core's remanence means that it retains a static magnetic field when power is removed. When power is then reapplied, the residual field will cause a high inrush current until the effect of the remanent magnetism is reduced, usually after a few cycles of the applied alternating current. Overcurrent protection devices such as fuses must be selected to allow this harmless inrush to pass. In transformers connected to long overhead power transmission lines, induced currents due to geomagnetic disturbances during solar storms can cause saturation of the core, and false operation of transformer protection devices.

Steel cores develop a larger hysteresis loss due to eddy currents as the operating frequency is increased. Ferrite, or thinner steel laminations for the core are typically used for frequencies above 1kHz. The thinner steel laminations serve to reduce the eddy currents. Some types of very thin steel laminations can operate at up to 10 kHz or higher. Ferrite is used in higher frequency applications, extending to the VHF band and beyond.

Vocabulary

lamination – пластина
E-shaped – Ш-образний стержень
C-core – U образний стержень
laminated – шихтований, пластинчатий
interleave – прошаровувати
wedging – розклинювання
overlap – накладання, перекривання
grain – структура
remanence – залишкова магнітна індукція, залишкова намагніченість
strip – штаба, стрічка
grind – шліфувати
strap – скоба
residual – залишковий
fuse – плавкий запобіжник
band – діапазон частот

Task 5. Answer these questions about the text.

1. What shape of pieces has a typical laminated core?
2. What fashion are the laminations stacked in?
3. How is a second gap formed between the E-pieces of the core?
4. Why are the E-pieces pressed together?
5. Is the effective gap width very large or very small?
6. What has the flux to do in order to work?
7. When does a saturation occur?
8. What will increase the overlap?
9. How can an air gap be created in that case?
10. In which way is the C-core made?

Task 6. Work in pairs. Ask your partner to tell about advantages and disadvantages of steel cores.

Text E

Windings

Before reading the text

Task 1. Match each phrase in the list on the left with the appropriate meaning on the right.

1. magnet wire	a) перемикач вихідних обмоток трансформатора
2. strip conductor	b) багатожильний провід
3. multiple-stranded conductor	c) перемикач вихідних обмоток трансформатора під напругою
4. tap-changer	d) обмоточний провід
5. on-load tap changer	e) штабовий (стрічковий)провідник

Task 2. Translate these phrases from the text.

very heavy currents; high frequency transformers; skin effect losses; low power frequency; high-current windings; voltage regulation; distribution circuit.

Task 3. Try to answer if the application of the transformer depends on the material used for the windings. Give some examples.

Task 4. Read the text, translate it and check your answer.

The wire of the adjacent turns in a coil, and in the different windings, must be electrically insulated from each other. The wire used is generally magnet wire. Magnet wire is a copper wire with a coating of varnish or some other synthetic coating. Transformers for years have used Formvar wire, which is a varnished type of magnet wire.

The conducting material used for the winding depends upon the application. Small power and signal transformers are wound with solid copper wire, insulated usually with enamel, and sometimes additional insulation. Larger power transformers may be wound with wire, copper, or aluminum rectangular conductors. Strip conductors are used for very heavy currents. High frequency transformers operating in the tens to hundreds of kilohertz will have windings made of Litz wire to minimize the skin effect losses in the conductors. Large power transformers use multiple-stranded conductors as well, since even at low power frequencies non-uniform distribution of current would otherwise exist in high-current windings. Each strand is insulated from the other, and the strands are arranged so that at certain points in the winding, or throughout the whole winding, each portion occupies different relative positions in the complete conductor. This "transposition" equalizes the current flowing in each strand of the conductor, and reduces eddy current losses in the winding itself. The stranded conductor is also more flexible than a solid conductor of similar size is.

Windings on both the primary and secondary of power transformers may have external connections (called taps) to intermediate points on the winding to allow adjustment of the voltage ratio. Taps may be connected to an automatic, on-load tap changer type of switchgear for voltage regulation of distribution circuits.

Vocabulary

coating – покриття
varnish – лак
enamel – емаль
strand – жила, скручувати
transposition – переміщення
tap – відгалуження, відвід
switchgear – комутаційний пристрій, розподільний пристрій

Task 5. Answer these questions about the text.

1. What kind of wire is generally used for windings?
2. What does the conducting material used for windings depend on?

Task 6. Find the wrong statement.

1. Primary and secondary windings of power transformers may have external connections.
2. Primary and secondary windings of power transformers may have internal connections.

Task 7. Work in pairs. Ask your partner to tell about the wires used for:

– small power transformers;
– larger power transformers;
– very heavy currents;
– high frequency transformers.

Text F

Insulation of windings

Task 1. Before reading the text try to answer if any insulation is used in windings. Why?

Task 2. Read the text, translate it and check your answer.

The turns of the windings must be insulated from each other to ensure that the current travels through the entire winding. The potential difference between adjacent turns is usually small, so that enamel insulation is usually sufficient for small power transformers. Supplemental sheet or tape insulation is usually employed between winding layers in larger transformers.

The transformer may also be immersed in transformer oil that provides further insulation. Although the oil is primarily used to cool the transformer, it also helps to reduce the formation of corona discharge within high voltage transformers. By cooling the windings, the insulation will not break down as easily due to heat. To ensure that the insulating capability of the transformer oil does not deteriorate, the transformer casing is completely sealed against moisture ingress. Thus the oil serves as both a cooling medium to remove heat from the core and coil, and as part of the insulation system.

Certain power transformers have the windings protected by epoxy resin. By impregnating the transformer with epoxy under a vacuum, air spaces within the windings are replaced with epoxy, thereby sealing the windings and helping to prevent the possible formation of corona and absorption of dirt or water. This produces transformers suitable for damp or dirty environments, but at increased manufacturing cost.

Shielding. Where transformers are intended for minimum electrostatic coupling between primary and secondary circuits, an electrostatic shield can be placed between windings to reduce the capacitance between primary and secondary windings. The shield may be a single layer of metal foil, insulated where it overlaps to prevent it acting as a shorted turn, or a single layer winding between primary and secondary. The shield is connected to earth ground.

Transformers may also be enclosed by magnetic shields, electrostatic shields, or both to prevent outside interference from affecting the operation of the transformer, or to prevent the transformer from affecting the operation of nearby devices that may be sensitive to stray fields such as CRTs.

Terminals. Very small transformers will have wire leads connected directly to the ends of the coils, and brought out to the base of the unit for circuit connections. Larger transformers may have heavy bolted terminals, bus bars or high-voltage insulated bushings made of polymers or porcelain. A large bushing can be a complex structure since it must provide electrical insulation without letting the transformer leak oil.

Enclosure. Small transformers often have no enclosure. Transformers may have a shield enclosure, as described above. Larger units may be enclosed to prevent contact with live parts, and to contain the cooling medium (oil or pressurized gas).

Vocabulary

layer – шар
immerse – занурювати
transformer oil – трансформаторне масло
corona discharge – коронний розряд
deteriorate – погіршувати
casing – корпус
seal – герметизувати
ingress – доступ
epoxy resin – епоксидна смола
impregnate – просочувати, промочувати.

Task 3. Answer these questions about the text.

1. Must the turns of the windings be insulated from each other? Why?
2. Is the enamel insulation sufficient for small power transformers?
3. What is usually employed between winding layers in larger transformers?

Task 4. Work in pairs. Ask your partner to tell about:

- transformer oil functions;
- alternative protection of the transformer windings by epoxy resin;
- terminals;
- enclosure

TEST (Unit 3. Transformer)

Choose the correct answer

1. A transformer consists of which of the following?
   A. A capacitor and an inductor
   B. An inductance and a resistance
   C. A parallel circuit
   D. Two or more coils and a magnetic core
   E. None of the above

2. A transformer with 100 turns in the primary winding and 25 turns in the secondary winding is which of the following?
   A. A coupling transformer
   B. An isolating transformer
   C. A step-down transformer
   D. A step-up transformer
   E. None of the above

3. Operation of a transformer at its designed voltage but at a higher frequency than intended will lead to
   A. Increase of the magnetizing current
   B. Decrease of the magnetizing current
   C. Load primary current
   D. Lower frequency
   E. None of the above

4. Operation of a power transformer at other than its designed frequency may not require the assessment of
   A. Flux
   B. Cooling

C. Voltages
D. Losses
E. Any of the above

5. Which of the following is not used for classification of transformers ?
A. Purpose
B. Frequency range
C. Power
D. Voltage
E. Friction

6. Eddy currents cause
A. Stopping aging of electrical steel
B. Frictional heating
C. Resistive heating
D. Vibrations within metalwork
E. Nothing

7. Which of the following doesn't contribute to losses in a transformer ?
A. Magnetostriction
B. Hysteresis losses
C. Stray losses
D. Self - inductance
E. Skin and proximity effects

8. What is the advantage of a toroidal core over E - and C - shaped core?
A. Magnetic – flux is always confined
B. Shorten the return path for the magnetic flux
C. Cause saturation of the core
D. Produce a buzzing sound
E. None of the above

9. Transformer oil doesn't serve as
A. Cooling medium
B. Part of the insulation system
C. Enamel insulation

D. Protection against the formation of corona discharge
E. None of the above

10. Transformers can be provided with
A. Dirty environments
B. Outside interference
C. Electrostatic shields
D. Breakdown
E. None of the above