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за спеціальністю "Електропривід та автоматизація загальнопромислових установок та технологічних комплексів"

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ELECTRIC MOTOR DRIVES

Where a machine is actuated by an electric motor, it is said to be electric driven, and the motor doing this is called the drive motor.

There are two methods that can be employed for driving the machines of a shop: in groups or individually. Group driving is from a line shaft carried in bearings. The line shaft is fitted with a multi-step pulley which serves to vary the speed of the driven machinery. The driven machinery can be stopped by switching off the drive motor. A serious drawback in this type of driving is that the line shaft has to be run at times when only a few or even a single machine is in operation. In individual driving, each machine is equipped with its own motor which may be arranged internally or externally to the driven machine. Group drive at one time was widely used. Individual drive, however, has so many advantages that it is used in practically all modern machines.

In some cases individually driven machines may have several motors, each executing a particular motion. A typical radial boring machine will, for example, have four motors, one for actuating the spindle, another for lowering and lifting the spindle arm, a third for slewing the spindle arm, and a fourth for supplying cutting fluid to the drill.

EXERCISES

I. Translate the text using the words given below:

English	**Ukrainian**	**Russian**
to actuate (to drive)	приводити в дію	приводить в действие
drive	привод	привод
drive motor	приводной електродвигун	приводной электродвигатель
shop	цех	цех
line shaft	проміжний вал	промежуточный вал
bearing	підшипник	подшипник

pulley	шків	шкив
drawback	недостача	недостаток
to equip	устатковувати, оснащувати	оборудовать, оснащать
arrange	встановлювати розміщувати	устанавливать, размещать
motion	рух	движение
radial boring machine	радіально-свердлильний верстат	радиально-сверлильный станок
spindle	шпиндель	шпиндель
cutting fluid	мастильно-охолоджувальна рідина	смазочно-охлаждающая жидкость
to slew	повертати	поворачивать

II. Read aloud the following words:

[i:] machine, even, each, speed

[ou] motor, own, only, lowering

[ɪ] spindle, lifting, switching, equip

[ɛə] bearing, vary

III. Translate the following groups of words into Ukrainian. Mind the stress.

to employ- employee (n.), employer (n.), employment (n.), employed (adj.)

to vary- variable (adj.), variety (n.), variability (n), varied (adj.)

to equip- equipment (n.), equipped (adj.)

to execute- executer (n.), executor (n.), executive (adj.)

IV. Find in the text the synonyms to the following words:

shortcoming, benefit, to fulfil, to turn.

V. Give three forms of the irregular verbs:

to drive, to run, to cut.

VI. Translate the Passive Infinitives into English:

називатися, застосовуватися, закріплюватися, оснащуватися.

VII. Complete the following sentences:

1. A machine is electric driven when it is ... .
2. The methods that are used for driving a machine are as follows ... .
3. The speed of the driven machinery is varied by ... .
4. The main disadvantage of group driving is ... .
5. Almost all modern machines are equipped with ... .
6. The motors of individually driven machines execute ... .

VIII. Make up sentences of your own using the following:

1) is actuated; 2) are employed; 3) is fitted; 4) is stopped; 5) is run; 6) is equipped; 7) is used.

IX. Answer the questions:

1. How are the machines of a shop driven?
2. What is a multi-step pulley used for?
3. Is the driven machinery stopped by switching off the drive motor?
4. What is each machine equipped with in individual driving?
5. Why is an individual drive widely used?
6. What motions does every motor of a radial boring machine execute?

THREE - PHASE ASYNCHRONOUS MOTORS

PART I

The three-phase asynchronous explosion-proof electric motors with a squirrel - cage rotor of 4 to 100 kW are designed for driving pumps, fans, winches and other mechanisms operating in a medium containing explosive gases, vapours and mixtures.

Motors are connected to the driven mechanism through a flexible coupling or a gearing. 3,000 r.p.m. motors are connected through a coupling.

A V-belt transmission reduces the service life of the bearings. The V-belt transmission may be used only after a special permission.

In case the motors are connected to the driven mechanism through a coupling, both shafts should be coaxial, otherwise the bearings will be subjected to excessive stress and the motor will be prematurely put out of service.

The motor should be earthed. A special screw set on the frame cantilever is used for this purpose. In the case of motors connected to the supply line by an armoured cable the armour should be earthed. A special screw is provided in the box end flange for this purpose.

When installing watch the cooling system:

1. The fan cap grid of motors should not be covered by the neighbouring parts of the coupled mechanism since a free exhaust should be provided to the cooling air.
2. The motors should be provided with a free air circulation over their body. It is not advisable to place the motor under a housing, in a tube, etc., since this increases the overheating and reduces the motor power.

After finishing installation check that the rotation of the motor is free (when turned by hand).

EXERCISES

I. Translate the text using the words given below:

English	**Ukrainian**	**Russian**
squirrel-cage motor	короткозамкнений ротор	короткозамкнутый ротор
winch	лебідка	лебедка
coupling	муфта, спряження	муфта, сопряжение
gearing	зубчаста передача	зубчатая передача

r.p.m.	(число) обертів в хвилину	(число) оборотов в минуту
shaft	вал	вал
axial	співвісний	соосный
to subject	піддавати	подвергать
screw	гвинт	винт
frame cantilever	укосина станини	укосина станины
supply line	сітка	сеть
armoured	броньований	бронированный
flange	фланець	фланец
grid	решітка	решетка
exhaust	вихід	выход
housing	кожух	кожух

II. Read aloud the following words:

[ɪ] asynchronous, increase

[ai] design, supply, provide

[ʌ] coupling, cover

[æ] coaxial, flange

III. Translate the following groups of words into Ukrainian:

to explore - explosion (n.), explosive (n., adj.), explosible (adj.)

to reduce - reduced (adj.), reduction (n.), reductive (adj.)

IV. Find in the text the sentences with Participle I and translate them into Ukrainian.

V. Complete the following sentences:

1. The purpose of the three- phase asynchronous motors is to ... .
2. Connection of motors is done through ... .
3. If the shafts are not coaxial, the bearings ... .
4. One should watch the cooling system when we ... .
5. Motors should not be placed under a housing because ... .

6. It's necessary to check that the rotation of the motor is free when we ... .

VI. Make up sentences of your own using the following:

1) are designed; 2) are connected; 3) will be subjected; 4) should be earthed; 5) is used; 6) should be covered; 7) should be provided.

VII. Ask questions to the text.

VIII. Make up a plan to the text.

IX. Retell the text according to the plan.

PART II

Maintenance. Carry out inspection of the motor in operation. Check periodically the operation duty, the heating, the condition of the contacts and see that motor is clean. Continuous current and voltage overload of the motor is not allowed.

The periodicity of technical inspections is determined depending on the operating conditions but it should be done not less than once, every two months. When making inspections clean the motor, check the adequacy of the earthing and the connection between the motor and the driven mechanism.

The periodicity of planned preventive repairs is determined depending upon the operating conditions but not less than once a year. In the course of planned preventive repairs disassemble and clean the motor and replace the bearings, if necessary.

The grease in the bearings should be changed in normal operation after 4,000 hours but not less than once a year. Before stuffing the bearing with new grease wash it thoroughly in benzine. Fill with grease 2/3 of the chamber volume.

If a part having surfaces involved in explosion-proof couplings (frame, shield, internal labyrinthine cover, box body and cover) is to be treated by machining or welding processes, the part should be subjected to a control hydraulic test.

EXERCISES

I. Translate the text using the words given below:

English	Ukrainian	Russian
duty	режим	режим
adequacy	надійність	надежность
inspection	огляд	осмотр
preventive	профілактичний	профилактический
grease	мастило	смазка
to stuff	наповнювати, набивати	наполнять, набивать
body	корпус	корпус
to machine	обробляти на верстаті	обрабатывать на станке
to weld	зварювати	сваривать

II. Read the words paying attention to their stress:

a'synchronous, trans'mission, prema'turely, 'cantilever, 'maintenance, insta'llation, 'over'heating, 'adequacy, laby'rinthine, sub'ject, ma'chining, 'process.

III. Study the following groups of words paying attention to the word - building and translate them into Ukrainian:

periodical - periodically - periodicity; inspect - inspection; operate - operation -operating; connect - connection; load - overload; prevent - preventive; assemble -disassemble; place - replace

IV. Make up your own sentences with the words given in ex. III.

V. Give three forms of the irregular verbs:

to see, to do, to make, to drive.

VI. Find in the text the words with «ing» endings and define the parts of speech.

VII. Ask questions to the text given.

VIII. Give the main idea of each passage.

IX. Retell the text using the key words:

checking, technical inspection, preventive repairs, grease change.

FAULTS IN OPERATION AND THEIR ELIMINATION

Faults	Cause	Eliminating
The motor doesn't run up when starting and it hums	No voltage on one of the phases	Locate and eliminate the break of circuit
The motor hums and is overheated in rotation	Interturn short circuit or short circuit between two phases	Repair the windings
Increased overheating of windings	Motor overload	Decrease the load to the rated value
Increased overheating of bearings	Wrong alignment of motor with mechanism	Check the alignment, obtain coaxiality of shafts
Lowered insulation resistance	Dirty or damp windings	Disassemble the motor, clean, blow and dry the winding
Excessive vibration	Insufficiently firm foundation or misalignment of motor and driven mechanism shafts	Eliminate the cause
Knock on the fan end	Friction between the fan and guiding housing surfaces resulting from housing displacement	Correct the position of the housing and fasten it reliably

EXERCISES

I. Study the table using the following words:

English	Ukrainian	Russian
to hum	гудіти	гудеть
rotation	обертання	вращение
interturn	міжвитковий	междувитковый
winding	обмотка	обмотка
rated value	номінальне значення	номинальное значение
alignment	центрівка	центровка
friction	тертя	трение

II. Read the pairs of words:

an 'increase - to in'crease; a 'decrease - to de'crease

Give your own examples of such pairs of words.

III. Learn the table and define the causes of different faults and ways of their elimination.

IV. Discuss the fault, the cause, the fault elimination in operation following the pattern:

St. 1: What happens (will happen) if the motor doesn't run up when starting?

St. 2: The reason is no voltage on one of the phases.

St. 1: What should be done to eliminate such a fault?

St. 2: To eliminate it one should locate and remove the break of circuit.

You are allowed to use your own pattern.

A MICROPROCESSOR CONTOLLER FOR P.W.M. INVERTERS

PART I

Three-phase induction motors are relative newcomers to the railway traction environment. Their use has until recently been prevented by the absence of suitable power conditioning equipment. Manufacturers are now

able to provide variable frequency inverters of both voltage - and current-source types which are capable of meeting traction demands.

Voltage-source inverters operating with six-step switching information have the following undesirable features arising from the waveform of their terminal voltages:

(a) Sixth-harmonic torque pulsations are produced which may excite mechanical resonances in the motor mounting. The torque pulsations also prevent smooth operation of the motor at low speeds.

(b) The induction motor currents have a high harmonic content causing undue heating of the motor. This may necessitate derating the motor.

(c) Harmonic currents at the inverter input may cause interference with signalling circuits.

Systems using current-source inverters also suffer from the problem of torque pulsations. In this case, however, they may be ameliorated at low speeds by using d.c. link control but doing so exacerbates the problems associated with supply current harmonics.

Both voltage and current-source six-step inverters require a controllable d.c. source. P.W.M. inverters, however, have no such requirement and so the complexity of the drive system is reduced.

Voltage-source inverters operating with sine-wave P.W.M. switching information can produce terminal voltages whose harmonic content is significantly lower than that of a six-step inverter. Such a reduction in the level of harmonic currents would eliminate torque pulsation problems and reduce the harmonic loss in the motor. By a suitable choice of carrier frequency it is also possible to reduce interference to an acceptable level.

One disadvantage of sine-wave P.W.M. inverters is their inability to deliver the full voltage otherwise available from the inverter.

With these arguments in mind it was decided to develop a unit to provide a voltage-source inverter with sine-wave P.W.M. switching information but

with the added facility of providing six step P.W.M. switching signals which in the limit become conventional six step signals.

EXERCISES

I. Translate the text using the words:

English	Ukrainian	Russian
P.W.M. (pulse-width modulation)	широтно-імпульсна модуляція	широтно-импульсная модуляция
induction motor	асинхронний двигун	асинхронний двигатель
railway traction	рейковий транспорт	рельсовый транспорт
power-conditioning equipment	обладання для підтримання вимагаємої якості електроенергії	оборудование для поддержания требуемого качества электроэнергии
harmonic torque	момент від вищих гармонік	момент от высших гармоник
to derate	знижувати номінальні значення	снижать номинальное значения
to ameliorate	покращувати	улучшать
to exacerbate	заглиблять, поглиблять	углублять
sine	синус	синус

II. Read aloud the following words:

[e] relative, prevent, resonance, necessitate

[ju:] suitable, unit

[aɪə] environment, undesirable

[kw] frequency, require

[ei] capable, derating, ameliorate

[ɔ:] torque

[ɛə] variable

III. Find in the text the synonyms to the words given below:

characteristic, to install, to supply, to decrease

IV. Read and translate the following words of the same root and state the part of speech of each word:

relative-relate-related-relation-relational-relationship-relatively-relativity-irrelative

prevent- preventative- preventer- prevention- preventive

to necessitate-necessity-necessary-necessarily-unnecessary

interference-interfere-interfering

eliminate-elimination-eliminator-eliminable-eliminant

suffer-sufferance-suffering-sufferer.

V. Translate into English:

задовольняти потреби; струм живлення; відповідне обладнання; небажаний; становлення двигуна; при низькій швидкості; надмірний нагрів; проблема зв'язана з; джерело сталого струму; утрата від гармонік; звичайний.

VI. Complete the following sentences:

1. The use of three-phase induction motors has been prevented by ... .
2. Variable- frequency inverters that meet traction demands are of two types:...
3. The disadvantages of voltage- source six-step inverters arise from ... .
4. The disadvantages of curent- source inverters is ... .
5. The difference between voltage and current- source inverters and P.W.M.inverters is ... .
6. Pros and cons of sine- wave P.W.M. inverters are ... .

VII. Speak on:

a) the types of inverters:

b) advantages and disadvantages offered by P.W.M. systems.

VIII. Give a summary of the text in written form.

PART II

Carrier Frequency Constraints.

For any P.W.M. inverter the harmonic content of the inverter terminal voltages will be dominated by the carrier and its sidebands. Whereas the carrier frequency harmonics may be cancelled in the three-phase load the side bands are not.

Attenuation of the harmonic currents in the motor is affected solely by the total impedance of the leakage paths and is independent of the magnetising impedance or the loading of the motor. Depending upon the degree of attenuation, harmonic currents at sideband frequencies may be drawn from the supply with sufficient magnitude to cause interference with signalling circuits. It is therefore necessary to ensure that the carrier is confined to a band of frequencies so that no such interference can take place.

For the purposes of evaluating the system the arbitrary limits of 600-1250 Hz were imposed on the carrier frequency. These can be easily changed to meet the constraints of any particular system.

Inverter Constrains

Switching of active devices used in the inverter takes a finite interval. To ensure that no 'shoot-through' conditions arise it is necessary to apply asymmetrical delays to the switching logic thus allowing one device to be fully turned off before the other device in the leg is turned on. Furthermore the method used in controlling the active devices may require that a minimum on-time limit is imposed.

Sampling Constraints

Asynchronous sampling, where there is a non-integral relationship between the carrier frequency and the fundamental frequency, produces sub-synchronous harmonics. Due to the low frequency nature of such harmonics the induction motor presents them with a low impedance path. Depending on

the amplitude of the sub-synchronous harmonic voltages unacceptably large currents may result.

The problem of sub-synchronous harmonics is avoided by the use of synchronous sampling techniques. Here there is an integral relationship between the carrier frequency and the fundamental frequency. By making the ratio a multiple of three cancellation of the carrier takes place in the three phase load when the motor has no neutral connections.

EXERCISES

I. Translate the text using the following words:

English	Ukrainian	Russian
sideband	бічна смуга	боковая полоса
attenuation	загасання, послаблювання	затухание,ослабление
impedance	повний опір, імпеданс	полное сопротивление, импеданс
leakage path	канал витікання	канал утечки
magnitude	амплітуда	амплитуда
leg	вітка	ветвь
on-time	час включення	время включения

II. Read aloud the words given below:

[ɔ] dominate, content, harmonics

[æ] cancel, magnitude, magnetize, evaluate

[ei] attenuation, delay, nature

[i:] impedance, technique, frequency, leakage

[a:] arbitrary, path

[ai] finite, supply, confine, device, apply

[ɪ] integral, sufficient, signal

[ʃ] ratio, ensure, relationship

III. Read and memorize the following synonymous words:

to cancel- to call of; solely- only; total- complete; to supply-to provide; sufficient- enough; to take place- to occur; to change- to vary; to turn on- to switch on; to require- to need; relationship- link, connection; to avoid- to get out of.

IV. Translate the predicates that in the Passive into Ukrainian:

will be dominated, is affected, may be drawn, is confined, were imposed, can be changed, is turned on, is imposed, is avoided.

V. Reproduce the situations from the text in which the verbs of Ex. IV are used.

VI. Answer the following questions:

1. What is attenuation of the harmonic currents in the motor affected by?
2. Why is it necessary for the carrier to be confined to a band of frequencies?
3. When are asymmetrical delays to the switching logic applied?
4. How can one avoid the problem of sub-synchronous harmonics?

VII. Translate the text in written form.

PART III

The software.

Structured programming techniques were adopted to assist the development and maintenance of the program. Although inefficient in the utilisation of program memory, execution times are enhanced by the use of structured programming and this was of great benefit in this application.

The program can be divided into six functional blocks. The first block is used only after a power-on reset has been initiated with the remaining five controlling the generation of the switching information.

'NEXTMP' is the only section of the program where separate code exists for the two modes of operation, the route through the block being selected

according to such criteria as amplitude demand, frequency demand and hysteresis.

If sine-wave P.W.M. switching is selected then it is necessary to access the look-up tables containing the waveshape data. For two of the three phases vectors are available which contain the addresses at which the data is to be found, these being calculated in another section of the program. Having obtained the base mark/period data the amplitude demand is used to modify these data. With the actual mark/period ratios for two of the phases now calculated the third is obtained by subtraction to ensure a balanced set of voltages.

Selection of the six-step mode requires no look-up table however the same vectors that are used to access the waveshape data are used in this mode to determine the sign of the fundamental voltages for each of the three phases. It is still necessary to use the amplitude demand to calculate the mark/period ratios although only one calculation is required since the ratios for the remaining phases will either be the same as or the complement of the first depending on the sign relationship of the fundamentals.

In both modes of operation, once the mark/period ratios have been calculated the minimum on-time limits imposed by the inverter are enforced.

I. Read the text paying attention to the pronunciation of the following words:
   [ei] maintenance, data, remain
   [e] separate, address, development
   [i:] frequency, hysteresis, technique, reset
   [æ] access, calculate, subtraction, balanced
   [ʃ] efficient, initiate

II. Make up all possible words adding different prefixes and suffixes and state the part of speech of each word:
   efficient (adj.), execution (n.), application (n.), divide (v.), exist (v.), separate (adj.), determine (v.), control (v.)

III. Find in the text the synonyms to the following words:
   to use, to fulfil, to increase, advantage, use, to choose, to include, to get, to demand.

IV. Give the plural form of the nouns:
   criterion, datum, ratio, hysteresis.

V. Find in the text the sentences with Participle I, define its form and translate into Ukrainian.

VI. Find in the text the sentences with the Absolute Participle Construction.

VII. Give the main idea of each passage.

VIII. Write a summary of the text.

MICROPROCESSOR BASED CONTROLLER FOR THE CONTROL OF POSITION AND SPEED OF D. C. SERVO-MOTOR

PART I

In many application where contour generation is needed both speed and position control of d.c. motor are essential. Minimisation of transition period, when changing motor speed, would improve the uniformity in following the required contour.

Design of a speed and position controller for a d.c. motor would involve the consideration of (a)system response time and (b)size of the controller. An efficient utilisation of the designed controller would, therefore, mean a careful consideration of hardware/software optimisation. The system design involves (a)selection of control strategy, (b)selection of sensing element for speed and position measurements and (c)design of control algorithm.

The available literature in the field of computer control ofd. c. motor indicates the use of digital control strategy. Digital transducers are commonly used in the sensing part and pulse width modulation in the actuation part. The use of control algorithm involving three term controller or an optimisation

technique is fairly known. The main drawback is that the more complicated the control algorithm, the more computer memory size and the longer execution period are required. Hence, controller size and response time are affected accordingly.

The development achieved in the field of microcomputer on a chip encourage their use for controlling processes with limited activities such as d. c. motor control. Careful utilisation of the chip resources should be made in order to achieve a suitable control strategy with powerful control algorithm.

EXERCISES

I. Translate the text using the words:

English	Ukrainian	Russian
uniformity	рівномірність, однорідність	Равномерность, однородность
contour	контур	контур
Digital transducer	датчик дискретної інформації	датчик дискретной информации
d.c.(direct current)	прямий струм	прямой ток

II. Read aloud the following words:

[e] essential, selection, measurement

[ei] application, changing,available

[ai] time, size, design

[i:] mean, field, technique, achieve.

III. State which words in group 1 are synonyms for the words in group 2:

1. to require, to include, to realise, essential, drawback, main, achievement
2. disadvantage, to contain, chief, to know, breakthrough, to need, important

IV. Translate the following phrases that in the Passive into Ukrainian:

contour generation is needed; digital transducers are used; control algorithm is known;

the more computer memory size and the longer execution period are required;

controller size and response time are affected.

V. Make up all possible words adding different prefixes and suffixes:

improve (v), use (n), know (v), application (n), response (n), affect (v), achieve (v), execution (n).

VI. Find in the text the sentence with two comparatives.

Make up your own examples using «the ... the ...».

VIII. Ask questions to the text given.

VIII. Give a summary of the text in written form.

PART II

The analysis of a d. c. servo-motor indicates that it can be approximated by a second order system when implemented as a closed loop speed control and third order system when used as position control. Since the position profile follows a standard procedure i. e. acceleration - traversing - deceleration, the control of a motor may take the form of speed control during acceleration and traversing. The influence of position control is then introduced at the beginning of the acceleration stage.

Based on these assumptions and using Pontryagin theorem for minimising the traveling period, the selected controller must be of the type “two levels controller” during the acceleration and traversing stages and “three levels controller” during the deceleration stage. Proper control over process would require dynamic computation of the duty cycle of the drive signal. However, this would be a lengthy process and requires large memory when the classical

analytical equations for the system are used. The controller response would accordingly be slowed down.

An alternative approach to the analytical solution is a semi-empirical method based on the use of the motor characteristics curves for precalculating the effective parameters and simplifying the required equations.

The factors involved in the computation for controlling the motor are given by the followings:

1. During the acceleration and traversing stages of the motion profile, the duty cycle of positive-to-zero voltage level for drive signal is made proportional to the demanded speed.

2. During the deceleration stage, the duty cycle of the negative-to-zero voltage level is influenced by the remaining travelling distance and the motor's instantaneous speed. The starting position of this stage is decided upon by the information collected on the motor load. Here, the acceleration distance is calculated dynamically and used as an indication of the load exercised on the motor shaft and, hence, as a deceleration distance.

EXERCISES

I. Translate the text using the words:

English	Ukrainian	Russian
servo-motor	серводвигун, сервомотор	серводвигатель, сервомотор
closed loop	замкнений виток	замкнутый виток
instantaneous	миттєвий	мгновенный

II. Read aloud the following words:

[ɔ:] order, form, accordingly

[æ] analysis, standard, traverse

[ei] based, stage, acceleration, deceleration, remaining, equation

[ai] type, cycle, drive

[ou] profile, process, over, approach, motor, load

[ɪ] simplify, influence

III. Find in the text the synonyms to the words given below:

to denote, to accompany, ascendancy, to present, reply, access, recognition

IV. Translate the following groups of words into Ukrainian:

to indicate (v) - indication (n.), indicating (adj.), indicatively (adv.), indicative (adj.)

to form - formation (n.), forming (n.), formed (adj.), formative (adj.)

V. Give three forms of the following verbs:

to take, to set, to give, to make

VI. Make up sentences with the following word-combinations:

Second order system, third order system, standard procedure, acceleration and traversing stages, deceleration stage, semi-empirical method, for controlling the motor.

VII. Answer the following questions:

1. How can one control a motor?
2. What types can the selected controller be of?
3. What is an alternative approach to the analytical solution based on?
4. What are the main factors involved in the computation for controlling the motor?

VIII. Retell the text using the answers to the questions given above.

Supplementary Texts

DC SERVO SYSTEMS CONTROL STRATEGIES: A COMPARATIVE SURVEY

Thanks to the great improvements in industrial microcomputers, programmed control system can be used for low level complexity applications, concurrently to analogous systems.

In robotics, new structures have been designed based upon a greater decentralization and hierarchization of the various functions, and on technological homogeneity. There is one module for each axis: it takes in charge all the functions specific to the axis, including positioning; it communicates with the trajectory generator that provides the position reference, with some other information and wait for information about the axis state.

It is quite to limit the number of the analogous sensors and to elaborate digitally the duty-cycle for the firing of the converter switches in order to ensure the greatest technological homogeneity. The advantages of such a structure are:

- A control decentralization leading to a new concept:
  the autonomous actuator module. According to the problem it can be used either alone or in relation with the higher hierarchical level. It can be adapted to its situation in the mechanical structure by using the software flexibility and thanks to the large range of performances of the CPU available on the industrial market (8 bit, 16 bit CPU, microcontrollers, arithmetic coprocessors...);
- So, more or less sophisticated algorithms can be implemented:
  - with parameters either constant of imposed by the higher hierarchical level: single position loop
    state variables loop.

  - with parameters dynamically adapted to the mechanical structure modifications.

Supplementary functions can also be added such as monitoring, security optimization.

The controlled system includes the power converter, the DC motor, the load and the sensors.

The power converter is a four quadrant transistor chopper supplied either by cells or by a rectifier that are shared by all the axes. Since its working frequency is much higher than the system bandwidth, an equivalent continuous model can be established; its linearity depends on the way the switches are fired. The possible non linearities are small enough to be considered as disturbances added to a linear model.

Proportional (P) controllers are commonly used. A permanent error exists that increases when the gain P is low and when the load torque is important. That is the main drawback of this kind of controller. However, if the error is lower than the digitalization error than the control performances are acceptable.

If the system phase margin is not large enough, it is necessary to use a lead compensation in order to avoid position overshoot. The static error can be indirectly lowered, as a gain increase is possible.

To compensate the load torque and to reduce the effects of dry friction torque the integration must be added in the controller design. In this case, a lead compensation avoids unstability but the controller adjusting range is lowered.

The implementation of such a controller with a microcomputer is quite simple. In particular, as the controller computation time is short two software organizations are possible:

- A short cycle time (one tenth of the loop constant time or less): the controller can be designed making a continuous approximation;
- A longer cycle time (that remains compatible with the system dynamic): other functions can be implemented during the sampling period. In this case, the controller can be designed with classical sampled techniques.

The simple position loop can be used for applications as trajectory generation (there, the speed is controlled). The system behavior is similar with a PLL system, in particular for the stability study in low speed range.

The function of each inner control loop is to compensate the disturbances effects as close as possible to their origin.

- Current loop:this loop has to limit the disturbance effects caused by:

-the power converter non linearity;

-the 300 Hz rectifier output voltage ripple;

-the cells or the filter output voltage variation.

The current controller bandwidth is imposed by these phenomena dynamic. It can reach 3 kHz that makes an efficient software controller difficult to realize with regard to the imposed sampling time.

The controller is either a proportional (P) or a proportional integral (P.I) one. Moreover, the power converter protection cannot be realized by a current reference limitation.

An active hardware protection for each switch is necessary (it is also the case for a single position loop).

- Speed loop: this loop has to compensate in static, the load torque and a part of the dry friction torque at each stopping point.

In dynamic, the speed loop has to lower the load torque variations. A proportional integral (P.I.) controller is chosen. Its bandwidth is tied to the disturbance dynamic imposed by the electromechanical time constant T_{em}.

For technological homogeneity reasons and in order to save a sensor, it seems interesting to use the position sensor output information for the speed measurement.

For high speeds, the speed information is obtained by counting the pulses number during a fixed sampling period.

For low speeds, this solution cannot be used because there is no information during the sampling period. For this speed range, another solution can be adopted which consists in measuring the period between two consecutive pulses. So, the speed control is either synchronized by the position sensor pulses or sampled with a constant period.

In any case, this kind of speed measurement cannot reduce the disturbance effects due to the load torque at low speed and a stopping point. If an analogous speed sensor is used, this control structure is satisfactory. Taking into account the required bandwidth a continuous or a sampled synthesis of the controller is possible; it depends on the sampling period determined by the system dynamic and the possible supplementary tasks are desired.

- Position loop: the position loop has to control the position of the system supposed insensible to the disturbances thanks to the inner loops.

A continuous synthesized proportional (P) or proportional derivative (P.D) controller is sufficient.

It can be noticed that this loop partially replaces the speed loop if it uses a digital speed measurement. In this case, the described structure with inner current and speed loops is very similar to the single loop structure.

Such a structure is a simple transposal of the classical analogous (or hybrid) structure. It preserves all the advantages of the structure that are:

-reducing of the disturbances effects;

-independent control of current, speed and position.

In return,the microprocessor based realization is quite difficult because different tasks are associated to the different loop. Each task has its own sampling period but all of them must be synchronized in order to avoid jitter phenomena.

The sampling periods can become very restricting (for example, the current loop). For these reasons, a good experience of sampling techniques, a good approach of the system and almost a good definition of the objectives that the control has to reach are needed for such a structure realization.

Two basic schemes of controller adaptation can be applied.

- If the process behaviour changes are detected by measurable variables (in our case, the angles of the articulated arm) the controller parameters can be computed taking into account the process parameters changes. This scheme is suitable to control the first joints of a robot, the loads variations depending in a first approximation only on the measurable angle between two adjacent segments of the mechanical structure.
- In the second scheme, "indirect adaptive control", process parameters are obtained by a recursive identification method using input and output measurements.