АВТОМАТИЗАЦІЯ ТА ІНТЕЛЕКТУАЛІЗАЦІЯ ПРИЛАДОБУДУВАННЯ

UDC 62-523.8, 621.38

ANALYSIS OF CIRCUIT SOLUTIONS FOR CHOOSING THE CONVERTER FOR A WALKING HEXAPOD ROBOT

Ilya Platov, Oleksii Pavlovskyi, Yuliia Pavlovska
National Technical University of Ukraine Igor Sikorsky Kyiv Polytechnic Institute, Kyiv, Ukraine
E-mail: a_pav@ukr.net

In this paper, DC converters for their use in the power supply system of a walking robot - hexapod are considered. The problem of energy conversion of robots of this class is an urgent problem, because the quality of the transformation will depend on the time of their autonomous operation, which in turn is an important factor influencing the range of applications of the robot. In addition to power supplies, the converter plays an important role in this. The less losses it will provide during the operation of the robot, the longer the robot will be able to move in space and perform useful work.

In this regard, the analysis of existing circuit solutions was carried out - from the simplest versions of converters based on discrete components to more complex with the use of special chips. Based on the analysis, the advantages and disadvantages of certain types of converters were identified, directly for their use in the power supply system of a walking robot - hexapod.

Among the main types of converters were step-down, as their efficiency is higher than the step-up. In addition, the analysis of the types of transducers showed that linear transducers have worse efficiency compared to pulse. In this regard, the main emphasis in the work is on pulse converters.

Of the latter were selected converters built using special chips designed for use in converters, because compared to other circuit solutions, they allow not only to obtain stable current and voltage in wide ranges, but also have the ability to adjust them, making it easy to test on the model work different servos without replacing the converter. Due to the high values of the output current for the developed layout, you can do with one converter, which reduces the cost and simplifies the design as a whole. In addition, such solutions, compared to others, have less weight and size, which is positively indicated by the possibility of placing on the hexapod additional equipment or payload that the robot can carry in the process.

***Keywords**: hexapod; step-down converter; servo drive; battery; circuit design; power supply; PWM controller; microcontroller; transistor; chip; efficiency factor.*

Introduction and problem statement

The development of autonomous power sources over the last decade has accelerated significantly. In particular, batteries, which have become, with their former dimensions, more capacity and power. The reason for this was the increase in demand of the consumer segment of the market and, as a consequence, the discovery of new battery production technologies, such as users of portable electronic equipment (smartphones, laptops, and other various gadgets operating on batteries), the appearance of electric cars, as well as the increasingly frequent use of quadcopters for various tasks. All this stimulated the leading manufacturing companies to produce more and more advanced batteries.

As for robotics, the problem of power sources did not bypass it, because modern trends in the development of robots are directed toward the development and improvement of walking quadropods and hexapods, which are no less likely to require as long and stable power for computing modules and actuators. But in addition to the power supply itself, the question of electrical power conversion remains important. The converter is an important link, because its efficiency largely determines the operating time of the powered device. All the advantages of powerful power supplies are lost when the wrong converter is selected, so the purpose of this paper is to review the various options for power supply voltage converters that will be optimal exactly for the walking robot hexapod.

The power structure diagram of the robot hexapod

A walking hexapod is a platform driven by limbs. There are many forms of platforms, as well as variants of placement of limbs, ranges of the angle of rotation of limb joints. In this case, the authors built a prototype, which is shown in Fig. 1 b, such a form factor was chosen in order to get as large an area as possible for placing useful equipment.

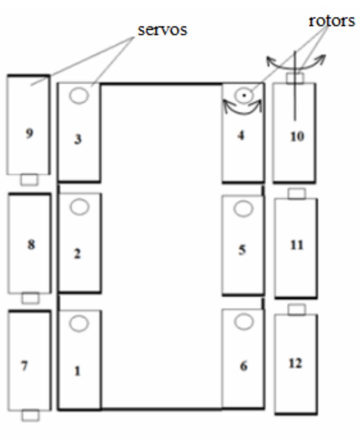
The positions of servo drives are shown

functionally in Fig. 1 a. Each drive was numbered clockwise, in this case the drives responsible for turning the limb in the horizontal plane have numbers from 1 to 6, and the drives of limb lifting from 7 to 12. It is worth noting that the minimum and sufficient number of degrees of freedom for limb motion is 2, which was realized using a pair of servo actuators [1-2].

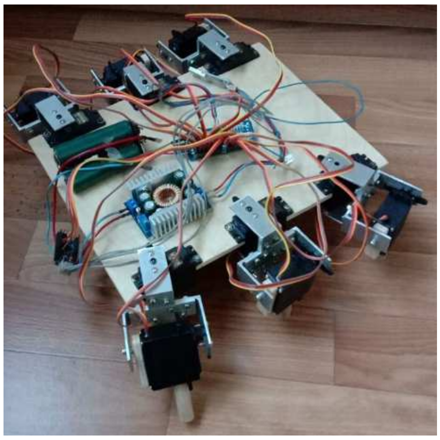
To provide efficient power supply to the hexapod, a circuit was developed, which is functionally shown in Fig. 2. For the model there were used MG-995 servo drives, the current consumption of which, according to measured data, is about 1.6 A at a load on the shaft of 9 kg/cm. A peculiarity of this circuit is the duplication of a power supply for the servos, because a quite powerful source with a voltage of 6 V and a maximum current of 1.5 × 12 = 18 A (this current will be consumed by the simultaneous maximum load of all drives) is needed to power 12 servos.

Of course, since the robot moves using different gaits, in real conditions the consumption will be much less, because, for example, when using a tripedal gait, 3 servos are simultaneously engaged at each step iteration, as shown in [2]. Thus, a power supply with a current of 1.5 × 3 = 4.5 A and a voltage of 6 V is enough.

In addition to servo drives, various sensors installed on the hexapod (accelerometers, cameras, touch sensors, etc.), microcontroller and PWM controller require power [3]. The PWM controller PCA9685 and Arduino Atmega-328p microcontroller are used in this layout. The module boards, on which these controllers are located, with voltage regulators are equipped. But the power line of the PCA9685 servo drives is not stabilized and to achieve the maximum torque on the shaft it is necessary to supply 6 V to it.



a)



b)

Figure 1. Servo placement: a) The positions of servo drives; b) Prototype of hexapod

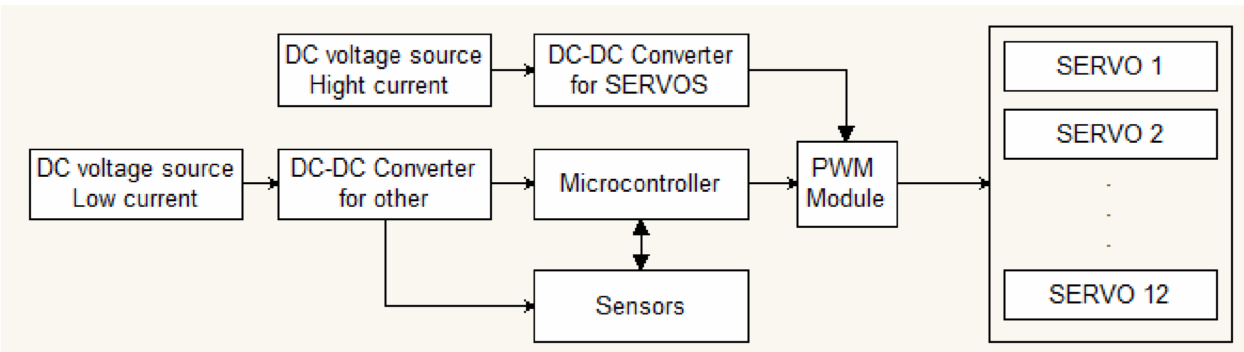


Figure 2. Functional scheme of hexapod power system

Therefore, it is necessary to have a separate converter for the servo power supply and for the computing core. Based on the previous works, the separate power supply for the power part (servo drives) and the computing part was realized [4].

Modern Li-Ion battery format 18650 has a voltage of 4.2 V and a maximum current of up to 30 A, since the voltage of one battery is not enough to power the servos, a DC voltage converter is needed [5]. The available converters can be divided into two main classes: step-up and step-down converters. Of the available research in the field of direct voltage converters it is worth highlighting the work [6], which examines the efficiency values of various converters and for step-down converters its value is maximum. Since the ultimate goal is to minimize losses in the power circuits, in this paper, only step-down converters will be considered, as the most energy-efficient.

Analysis of converter circuits

Today the market offers a wide range of different converters, both AC and DC, high and low power. The use of one or the other depends on the supply voltage, which in turn depends on the layout. The use of one or another converter depends on the supply voltage, which, in turn, depends on the arrangement of power sources. A series connection increases the voltage, while a parallel connection increases the capacity of the whole battery. Therefore, for robotics applications, a balance must always be struck between the capacity, power, and mass characteristics of the batteries. The choice of switching option is determined by the components of the robot that require one or the other voltage.

Since a walking hexapod can be built on the basis of common and available components, the power supply unit is accordingly not a special purpose source, i.e. it does not require any unique functionality, in this connection let us consider popular voltage converter circuits, which can be assembled from discrete components. This approach will allow to universalize the hexapod power supply system, as well as solve the issues of quick repair.

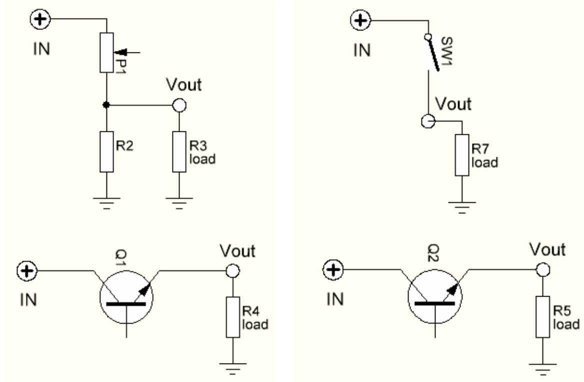
1) Transistor-based step-down converters.

In the simplest case, the step-down converter is a circuit, shown simplified in Fig. 3 a, which is an adjustable voltage divider. The transistor operates in active mode and is adjusted so that the voltage drop across the collector-emitter junction is in the desired range. Fig. 3b shows the circuit of pulse converter, the main difference of which is regulation of output voltage by changing the fill factor of PWM signal, equal to the ratio of output voltage to the input voltage as:

$$D = \frac{U_{out}}{U_{in}} . \quad (1)$$

The higher the coefficient, the higher the voltage will be at the load.

The PWM signal for the pulse mode can be obtained from a crystal oscillator or a microcontroller used as the computing core of the robot.



a) b)

Figure 3. Voltage step-down converters on transistors: a) linear converter; b) pulse converter

The main disadvantage of the linear converter is the dependence of the efficiency on the input and output voltage difference [8]. On this basis, in this paper, the main emphasis is placed on pulse converters, as they are devoid of this disadvantage.

To begin with, let's note that in general terms any converter without power amplification has the following form (Fig. 4).

In this case, the constant voltage source consists of batteries connected in series, parallel or mixed mode. The other parts are made as a printed circuit board of discrete SMD components to reduce the size of the whole device. Loads are limb actuators, control unit, sensors, etc. Schematic diagram of such a converter looks like diagram as on Fig. 5.

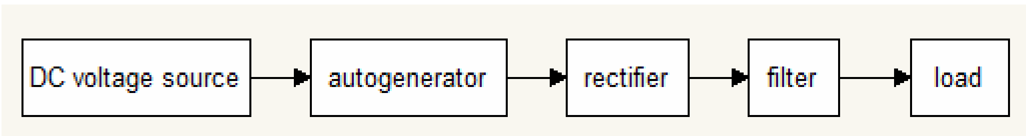


Figure 4. Functional diagram of the voltage converter

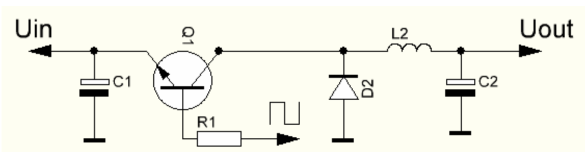


Figure 5. Schematic diagram of a voltage step-down converter on a transistor

The DC-DC converter circuit shown in Fig. 3 consists of transistor Q1, which operates in the key mode, diode D2, input C1 and output C2 smoothing capacitors, inductor L2. The opening/closing of the transistor is done by a PWM signal. When the transistor is open, energy is stored in the coil. After the transistor is closed, the energy stored in the coil is given to the load via diode D2 due to the self-induction EMF.

This circuit has no short-circuit protection or current stabilization, so apart from simplicity it has no other advantages.

2) Step-down converters on specialized chips.

The simplest step-down converter on the chip is the converter on the MA7805KM (analogue-КР142ЕН5Б) Fig. 6 [8]. The maximum input voltage is 15V, the rated output voltage is 6 V, and the maximum output current is 2 A, which satisfies the hexapod design described above. Using such a converter is not the best circuit solution because this type of chips implements a linear step-down converter with a stabilizer, and as mentioned above, its efficiency is worse than the pulsed ones [5].

Thus, this type of converter can be used in circuits where losses can be neglected. However, despite its simplicity, due to losses, its use for a hexapod will adversely affect the operating time, so its use in robotics is not advisable.

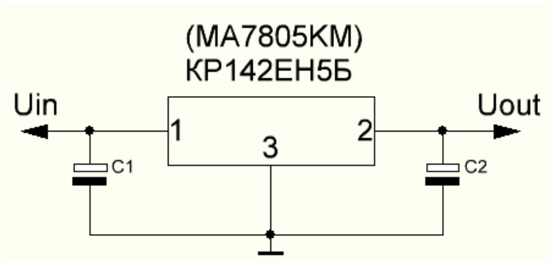


Figure 6. MA7805KM step-down converter.

The best solution in terms of its characteristics is a pulse converter on one of the specialized chips, such as XL4016 (Fig. 7) [9].

The appearance of such transducers is shown in Fig. 8, a and Fig. 8, b.

Microcircuit XL4016 – pulse DC-DC converter, input voltage range 5-40 V, output 1.2-35 V, the output current – 8 A, when using forced cooling up to 12 A. The voltage converter based on this circuit has the highest efficiency of all the types of converters considered above, and also allows to regulate the output voltage and current, which makes it a convenient circuit solution when testing different types of drives on the robot layout. Due to the high output current, only one converter can be used for all servos, which saves space and allows the robot to carry more payload.

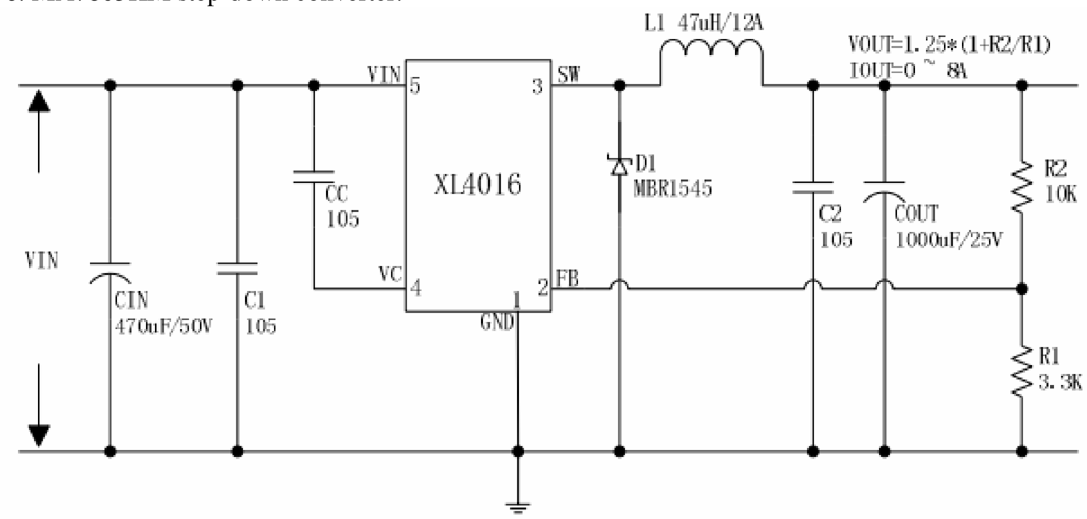


Figure 7. Schematic diagram of the pulse step-down converter

a) b)

Figure 8. Converters on specialized microcircuits: a) 5A step-down converter; b) 12A step-down converter

Thus, among all the above circuit solutions, the pulse step-down converter based on special chips is the best and most energy-efficient solution.

Conclusions

In this paper, we considered various circuit solutions for selecting a DC converter for a walking robot – hexapod. As a result of comparing the characteristics of step-up and step-down converters, the latter were chosen, since they have the highest efficiency.

The analysis of variants of converters based on discrete and integrated components showed that the integrated ones, in addition to ease of installation, have better characteristics and capabilities, because they allow us to obtain a stable output current and voltage.

Among converters on microcircuits the pulse ones were selected, which have the best characteristics among all considered variants. Consequently, it is advisable to use pulse converters as the most energy-efficient, low-cost circuit solution to implement the power supply system for the walking robot hexapod.

Further research is planned to consider the possibility of modifying pulse converters to further increase their efficiency.

One of the options can be implemented by the implementation of the “sleep mode”, at the end of the active phase of movement, the microcontroller can issue power-off commands to all or a group of servos, the position will be held due to friction in the servo gearboxes.

References

[1]. I. M. Платов, О. М. Павловський, Д. О. Півторак, “Концепція створення керованих автоматизованих крокуючих платформ з чотирма кінцівками”, *Вісник НТУУ «КПІ» Серія приладобудуваня*, Вип. 59 (1), с. 79-86. 2020. DOI:10.20535/1970.59(1).2020.210023

[2]. I. Platov, O. Pavlovskyi, “Movement algorithm of an autonomous robot-hexapod for moving in narrow closed spaces”, *Bull. Kyiv Polytech. Inst. Ser. Instrum. Mak.*, is. 61(1), pp. 61–68, 2021. DOI:10.20535/1970.61(1). 2021.237103

[3]. PCA9685 [Online]. Available: https://cdn-shop.adafruit.com/datasheets/PCA9685.pdf

[4]. I. M. Платов, О. М. Павловський, “Гексапод для діагностики складних споруд та інженерних об'єктів. Система живлення”, на *XVI Всеукр. наук.-практ. конф. студентів, аспірантів та молодих вчених. Ефективність та автоматизація інженерних рішень у приладобудуванні*, Київ, 2020 р., с. 37-41

[5]. I. M. Платов, “Система живлення крокуючого гексапода”, in *The X International Science Conf. Topical issues, achievements and innovations of fundamental and applied sciences*, March 09 – 12, Lisbon, Portugal, 2021, pp. 331-336

[6]. R. W. Erickson, “DC–DC Power Converters”, in *Wiley Encyclopedia of Electrical and Electronics Engineering*, J. G. Webster, Ed., 2007. DOI:10.1002/047134608X.W5808.pub2.

[7]. DC/DC-преобразователи: принципы работы и уникальные решения Maxim Integrated. [Online]. Available: https://www.compel.ru/lib/134297

[8]. Стабилизаторы КРЕН142 фиксированного положительного напряжения [Online]. Available: https://static.chipdip.ru/lib/491/DOC001491784.pdf

[9]. XL4016 Datasheet. [Online]. Available: https://datasheetspdf.com/pdf-file/839856/Xlsemi/XL4016/1

УДК 62-523.8, 621.38

І. М. Платов, О. М. Павловський, Ю. О. Павловська
Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна

АНАЛІЗ СХЕМОТЕХНІЧНИХ РІШЕНЬ ПРИ ВИБОРІ ПЕРЕТВОРЮВАЧА ДЛЯ КРОКУЮЧОГО РОБОТА-ГЕКСАПОДА

У даній роботі розглядаються перетворювачі постійного струму для їхнього використання у системі живлення крокуючого робота – гексапода. Проблема перетворення енергії роботів такого класу є актуальною, оскільки від якості перетворення залежатиме час їхньої автономної роботи, що, у свою чергу, є важливим фактором, який впливає на спектр сфер застосування робота. Важливу роль у цьому, окрім джерел живлення, відіграє перетворюючий пристрій. Чим менші втрати він забезпечить у процесі експлуатації робота, тим довше робот зможе переміщуватися у просторі та виконувати корисну роботу.

У зв'язку з цим був проведений аналіз існуючих схемотехнічних рішень - від найпростіших варіантів перетворювачів, побудованих на дискретних компонентах, до більш складних із застосуванням спеціальних мікросхем. На основі аналізу були виділені переваги та недоліки різних типів перетворювачів, безпосередньо для їх використання в системі живлення крокуючого робота – гексапода.

Серед основних типів перетворювачів було виділено понижуючі, оскільки їх сучинник видатності вищій, ніж у підвищуючих. Крім цього, аналіз типів перетворювачів показав, що лінійні перетворювачі мають нижчий сучинник видатності, порівняно з імпульсними. У зв'язку з цим основний акцент у роботі зроблено саме на імпульсні перетворювачі.

З останніх були виділені перетворювачі, побудовані з застосуванням спеціальних мікросхем, розроблених для їх використання у перетворювачах, оскільки порівняно з рештою схемотехнічних рішень, вони дозволяють отримати стабільний струм і напругу в широких діапазонах, крім цього мають можливість їх регулювання, що дозволяє легко тестувати на макеті робота різні сервоприводи без заміни перетворювача. Завдяки високим значенням вихідного струму для розробленого макета можна обійтися одним перетворювачем, що здешевлює та спрощує конструкцію загалом.

Ключові слова: гексапод; понижуючий перетворювач; сервопривод; акумулятор; схемотехнічне рішення; джерело живлення; ШІМ-контролер; мікроконтролер; транзистор; мікросхема;коефіцієнт корисної дії.

Надійшла до редакції
11 квітня 2022 року

Рецензовано
28 квітня 2022 року