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Power Supply Concept for Mobile Robots in Bionic Assembly System

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Abstract

This paper presents a concept for autonomous energy supply for mobile robots in Bionic Assembly System (BAS). The main idea of this concept is battery swapping and charging station for mobile robots. Emphasis was placed on simplicity, safety and efficiency. Main focuses of this paper are detailed description of operation, battery charging process with implemented battery management system (BMS), mobile robot requirements and its implementation into the existing BAS concept.

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Keywords: energy supply; mobile robots; battery management system; Bionic Assembly System

1. Introduction

Globalization brings challenges to today's production companies. One of the main reasons is increase of product variability. Producer should be able to adapt to a quick changing market situation. That means produce more types of products with smaller quantities of production. There is one possible way for the manufacturer how to bring the production to a new level and adopt for the future changes. This could be done through creation of new type of system, which will be more effective and adaptive to bring value to the company under different market conditions. This would help to reduce the resources consumption, increase the utilization of machinery and make the system more robust to the elements failures.

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Intelligent Manufacturing Systems group from Vienna University of Technology makes a constant research and development of a concept of Bionic Assembly System (BAS), which is based on self-organization - phenomena used by a nature. The description of working scenarios and strategies of the system is shown in [1], possible reconfigurations within the system in [2], modeling of mobile robot behavior in BAS is shown in [3].

Mobile robots are a key element of BAS. To gain their mobility which is one of the basic principles, batteries are required. Compromise between battery reliability, efficiency and weight must be achieved.

There are two main strategies for a mobile robot power supply. They are “one battery per robot” and “more batteries per robot”. In “one battery per robot” concept, one battery is designated for a robot. When battery charge is low, robot should perform charging process and be out of service in that period.

In “more batteries per robot” concept, there is a certain amount of batteries designated for all the robots in the system. Battery replacing instead of charging is present. This fact leads to the smaller amount and higher utilization of mobile robots. For this reason “more batteries per robot” will be considered in this paper.

2. BAS requirements for Battery Swapping Station

System which operates in a fully automated manner is required. Furthermore, more batteries should be charged at the same time. Nowadays, there are two known charging principles: conventional and wireless. Wireless charging is more elegant solution than conventional because there is no need for cables. For use in this system, there are issues such as low efficiency and slower charging.

Following requirements of the BAS, power supply concept is proposed. The focus was on quick and seamless battery swap. Battery swapping station is involved in communication within the assembly system. Furthermore, it has a capacity of 7 batteries and it is placed next to the pool of robots which can be seen on Fig. 1. This position is chosen because it doesn’t represent an obstacle in system’s layout. If necessary, the position of the station can be changed.

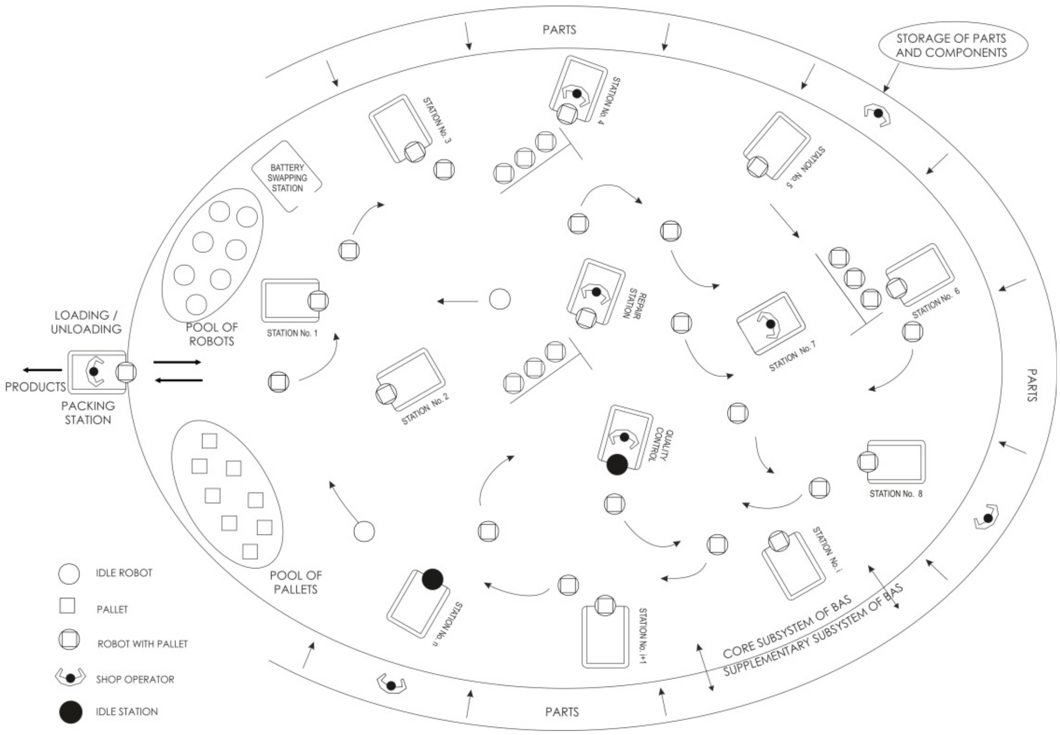

Fig. 1. Position of the battery station in the BAS layout

3. Available solutions

There are solutions which are designed and constructed specifically for low powered robots. As shown in [4], vertical rotating plate combined with linear actuator is able to replace battery in a mobile robot. Actuator pulls the battery out from the robot and puts it in the storage which then rotates and sets a full battery in the same position from which it will be pushed in the robot. Furthermore, side cylinders prevent robot from moving. To sustain power on the robot while replacing, large capacitor is used in order to store charge and release it when empty battery is pulled out of. Overall, it is a good solution for small, low-power robots. Other solution shown in [5] uses different principle. It uses linear movement of battery packs in the charging station.

In general these solutions are designed for small robots. Mobile robots for BAS are required to transport high loads as well as make decisions autonomously. Therefore their power consumption is high. Available solutions are not designed for demanding powerful BAS robots. However, implemented construction solutions such as battery storage, charging process and battery replacement are used for further researching and implementing in this particular concept.

4. Battery swapping station

The main idea of this concept is a combination of battery swapping and charging stations for mobile robots. Battery swapping station structure can be seen on Fig. 2. This paper is focused on the hardware solution for the proposed concept.

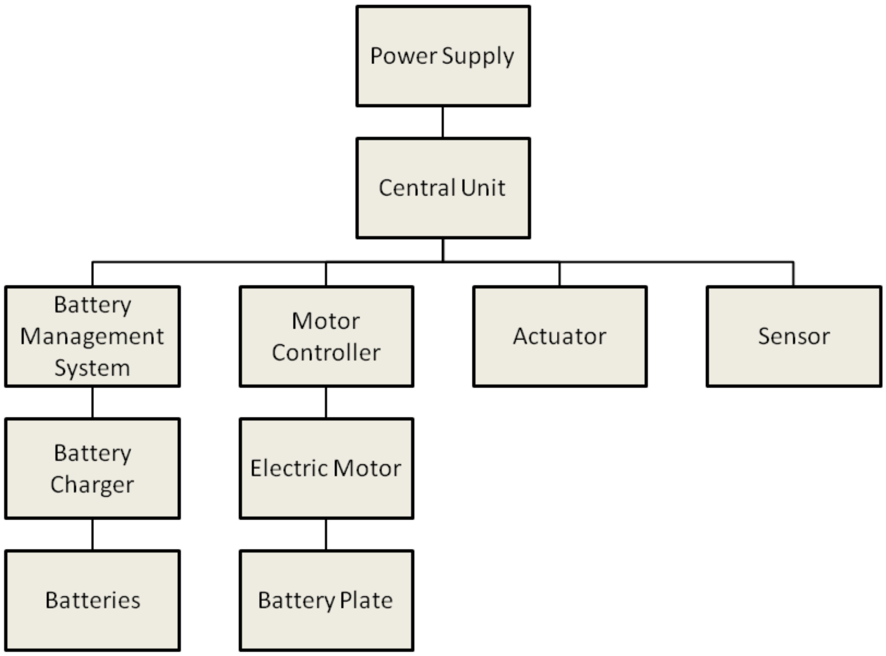

Fig. 2. Block scheme of the battery swapping station

The station consists of two main subsystems: mechanical and electrical. Mechanical subsystem covers the battery plugs from batteries to charger and transmission of mechanical energy from electric motor to battery plate. Electrical part covers the battery charging, battery management system, cables, electric motor control, sensor, actuator, central unit and power supply. The initial 3D concept, designed in Blender - open-source 3D computer graphics software can be seen on Fig. 3.

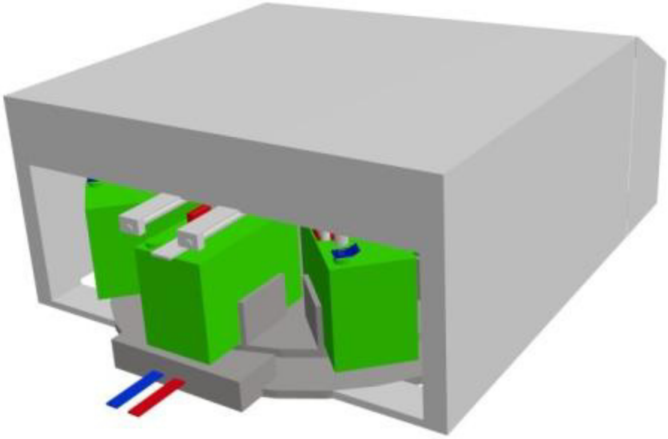

Fig. 3. Battery swapping station

5. Mechanical part of the battery swapping station

5.1. Contacts between battery and charger

Contact between battery and a charger is achieved through the connector which is supported on a spring in order to achieve a good connection with the battery due to the high currents. Since charger contacts are static and plate with batteries is rotating, achieving a contact with batteries needs to be done in both mechanically and electrically safe way. Concept is shown on Fig. 4. It can be seen that all contacts have a chamfered area turned to the upcoming batteries. Because they are suspended on the springs, the upcoming battery lifts up the contact. Chamfered area accepts the battery and provides transition to a charging ready position with reduced friction. In those moments, motor which drives the plate is coping with higher force and therefore needs to be involved in the calculations for the needed power. Each battery should have its own plug for battery management system. The number of pins on a connector depends on a number of cells inside the battery. That could be an occupation for future research because of the complexity of such systems.

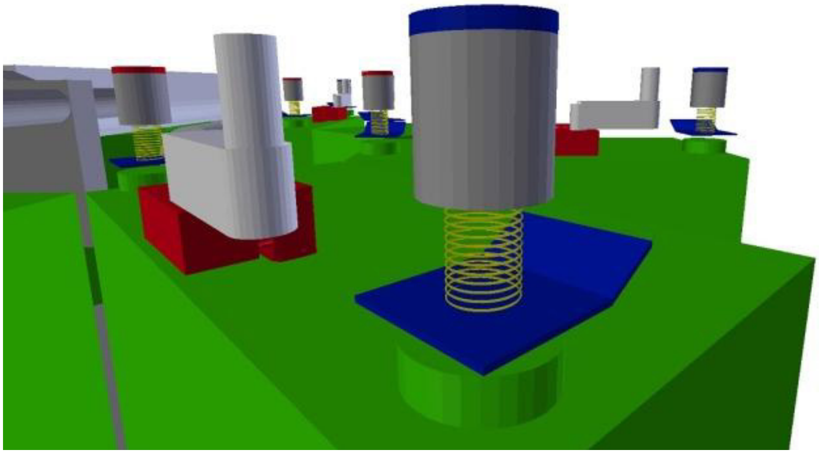

Fig. 4. Contact between battery and charger

As shown in Fig. 5. socket mechanism with two axis of freedom follows the plug on the battery while it moves along with. Joints are operated with springs in order to gain the primary state and wait for the next battery. These operations have to be done precisely because none of the pins on the connector should be unplugged. As mentioned before, it can affect the charging process.

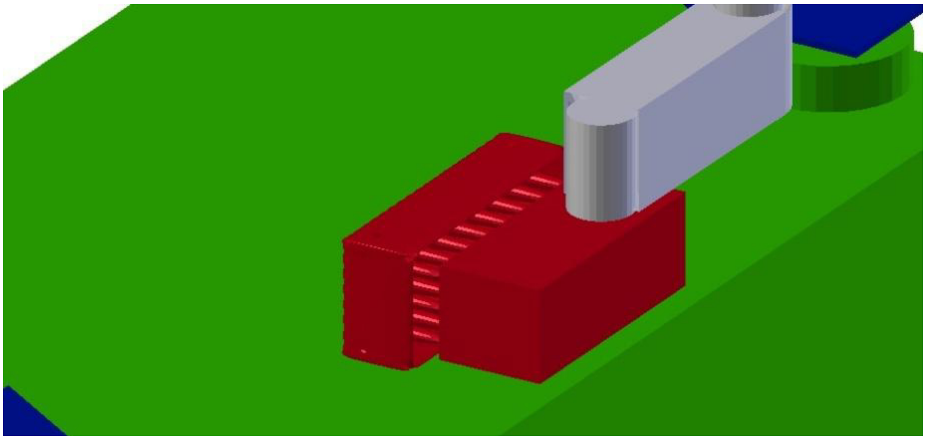

Fig. 5. Contact for a battery management system

5.2. Linear actuator

Linear actuator [6] is used for pulling the empty battery out of the robot and pushing the charged one into the robot. Its construction is simple; it is based on DC motor, cylinder and a piston with a screw. Controlling is same as in other DC motors. As shown in Fig. 6., actuator has implemented retractable grab at the end of the piston. It is required because once actuator covers the battery, grab needs to hold it once piston starts to go back. Together with a grab, limiter holds the battery on the other side assuring the same linear speed as the piston.

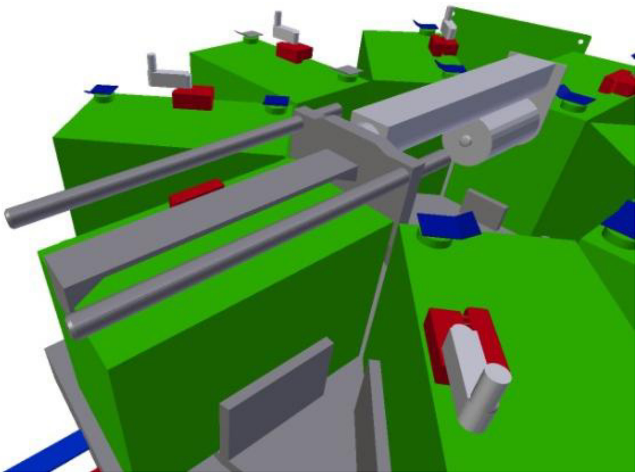

Fig. 6. Possible design of the actuator tool

Most today's actuators operate on the voltage of 12 V. Calculations needs to be made for getting the approximate force. Space inside the swapping station for the actuator is limited and therefore not all actuators in term of length are suitable.

5.3. Transmission

Both electric motor and rotating plate are connected with their own gears which are connected with timing belt and placed underneath the rotating plate in order to simplify the transfer of power. Therefore, from the upper side of the plate is now empty space which is used for placing a linear actuator. In this case, rotating plate should have speed of 1.5 rpm. Since motor is working at much higher speeds, reducing should be achieved by mechanic gears. On Fig. 7., electric motor is connected with a gearbox and by timing belt with the rotating plate's gear.

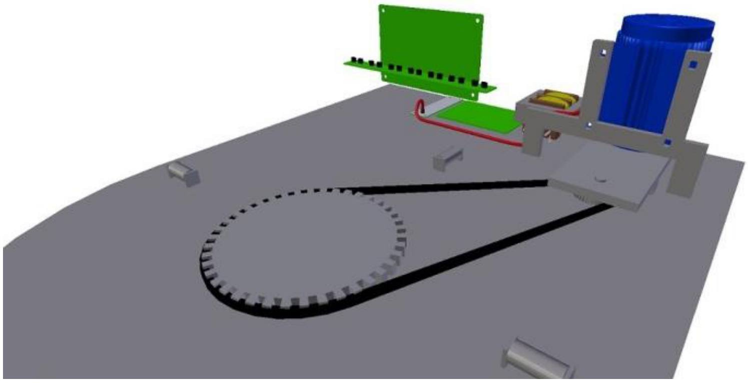

Fig. 7. Transmission system

5.4. Rotating plate

Rotating plate illustrated in Fig. 8., has 8 spaces of which 7 are designated for charging. It follows the principle that one space will always be empty and ready for acceptance of the empty battery. Plate will be fulfilled only in a period of rotating. As mentioned, it is a part of the electrical drive. As a result of this type of drive, batteries are operated by "first in first out" principle. That means, battery which was plugged in first will finish with charging and will be delivered to robot first. Each battery specified space has its own built in limiters in order to reduce a risk of accidental moving of the battery. It can happen because of possible external influences. Rotation of the plate should be slow in order to gain operation without sudden movements. Plate surface should be made of metal and a friction between robot and plate should be reduced in order to reduce the effort of the actuator. The rotating plate is supported by rolling element bearing in the centre and rolling cylinders on the sides. Rolling cylinders need to be short in order to track rotation of the plate without vibrations.

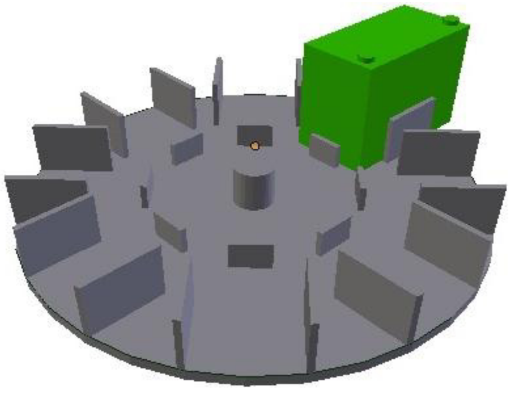

Fig. 8. Rotating plate

6. Electrical part of the battery swapping station

Battery swapping station has high demands for power due to fact that it manages the charging of 7 batteries with higher capacity. Therefore, electrical circuit must be able to withstand high currents. Emphasis should be placed on safety and durability.

6.1. Power supply

Power supply for battery swapping station is after being rectified divided into 3 different segments. There should be adjusted voltage for electric motor, battery charger and for the rest of the electronics. Voltage from the electric grid is rectified to a value that should be sufficient for charging the batteries and after that it is adjusted to further demands of electric motor, battery management system and other electrical circuits.

6.2. Charging

Charging process of more battery packs must be carefully supervised. At every moment, large differences between states of charge among batteries are present. For some types of batteries (e.g. lithium-ion, lithium-ion polymer or lithium iron polymer) it can cause damage. When one of the cells inside the battery reaches its maximum charged voltage, battery management system (BMS) must then balance the battery in order to maximize its capacity. It should do so by removing charge from the most charged cell until its voltage is low enough that the charger may come back on. It is important to notice that if the battery needs to be charged faster, charging current will be bigger.

6.3. Battery Management System

Battery Management System (BMS) according to [7] is used with the intent of taking care of batteries which are sensitive to charging and discharging. Its functions are: monitoring, protecting, estimating the battery state and maximizing performance. In this case it is very important to meet the following requirements:

- Prevent the voltage of any cell from exceeding a limit, by stopping the charging current
- Prevent the temperature of any cell inside the battery from exceeding a limit by stopping the current
- Prevent the charging current from exceeding a limit by reducing or stopping
- Preventing the discharging current from exceeding a limit by reducing or stopping

By appropriate electrical equipment, charging of all batteries in the station can be monitored. All data acquainted from measuring are multiplexed in a multiplexor and then sent to the battery management system central unit. Furthermore, data are then demultiplexed and analyzed following the requirements. This principle is used in order to reduce size and component count. As seen on Fig. 9., printed circuit board in the front represents the multiplexer and wide centrally located cable carries the multiplexed signal to the BMS circuit board.

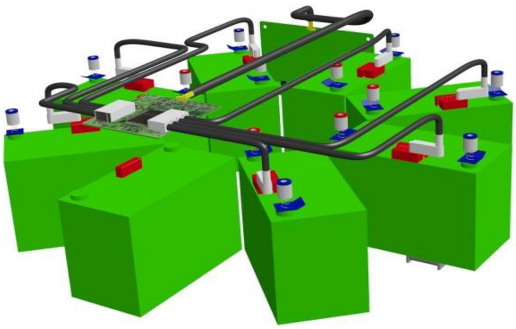

Fig. 9. Data multiplexer of a BMS

Charge can be interrupted if BMS sends the signal to the charger's electrical circuit. For example, when one of the battery cells reaches its maximum charged voltage, BMS must balance the battery to maximize capacity. It should do so by removing charge from the most charged cell until its voltage is low enough that the charger may come back on. Each time when rotating plate rotates for one place, new battery comes to the charging plugs. When battery comes to the next plug, it is important to first analyze charge state from the data of the BMS and then, perform charge if needed.

6.4. Electric Motor

The idea is that electric motor, located behind the rotating plate like on Fig. 11., drives the rotating plate when actuator pulls empty battery out of the robot in order to get the charged battery in designated position. For this purpose, DC motor with independent excitation can be used because it is simple to control with. Operation of the motor must be divided in three parts: acceleration, constant speed and deceleration.

Two-quadrant controller is the common type of DC motor controller. As shown in Fig. 10., it is composed from two transistors (Q1 and Q2) which are operated with pulse width modulation (PWM) control. If necessary, this controller can stop rotating plate using the DC motor. More about this controller can be found in [8]

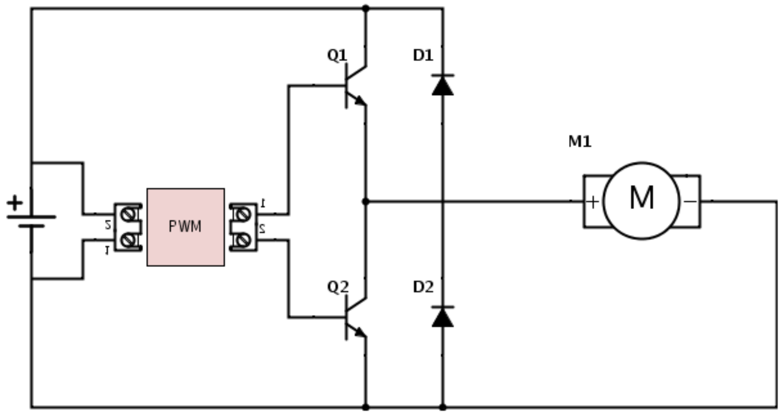

Fig. 10. DC motor controller

Motor controller together with a gearbox can provide required speed of rotating plate without torque losses. Controller can be used for gradual acceleration and deceleration.

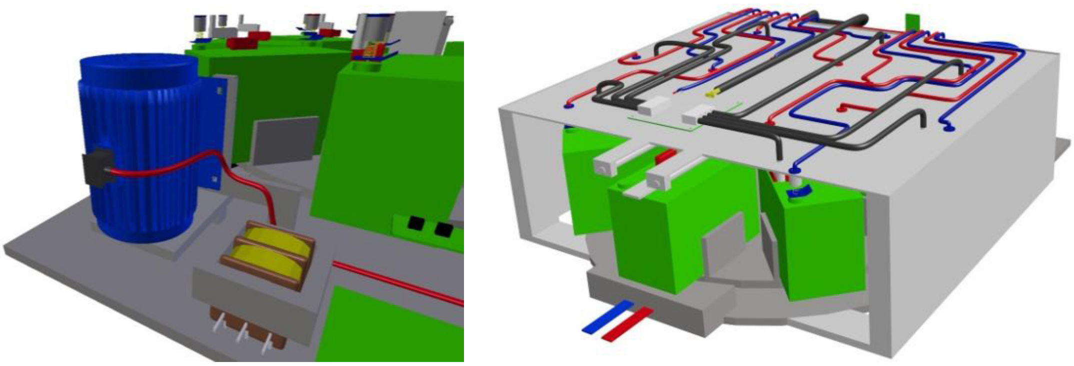

Fig. 11. (a) Possible location of the electric motor, (b) Cables

6.5. Cables

Special attention should be given to cables. Charger for example, uses high currents so cable sizing and insulation have to be tested for such operations. When performing cable sizing, expected load current, length and voltage must be taken in concern. Help can be provided from programs and various instructions such as [9]. Fig. 11(b) illustrates charger cables that are located above the batteries and inside the case.

7. Robot Demands

To gain fully autonomous operation, there are requirements which robot should meet. Battery storage must be compatible with swapping station. That means that there should be the empty space for undisturbed operation of the actuator. End position of the battery placed in a robot must be within a range of actuator's piston. Both robot's battery space and swapping station should be on a same level. Robot's approaching to the stationary position should be achieved by using proximity sensors placed on swapping station and robot. Holding in a static position is also important and by using robot's brakes it can be solved. Robot should also have the battery management system for monitoring the discharge.

In order to maintain power on the robot even in a period of battery replacing, there should be an electric contact with the station. When robot approaches to the exact position, extruded pins on the station (Fig. 12) get in contact with the pins on the robot and in that way maintain power supply to vital electric parts.

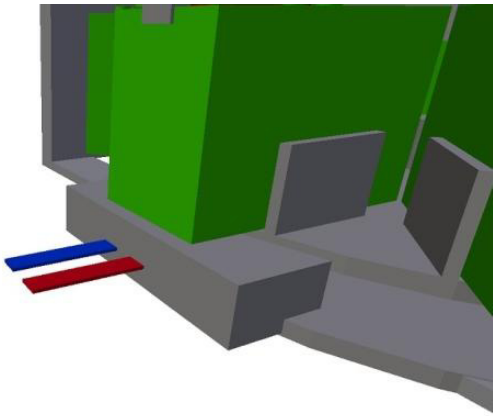

Fig. 12. Contact pins on the swapping station

8. Conclusion

Concept for autonomous energy supply for mobile robots in BAS was presented in this paper. The main idea of this concept is a combination of battery swapping and charging stations for mobile robots. Concept development included:

- General BAS requirements analysis
- Design of Battery Swapping Station concept
- Design of battery charging process with implemented battery management system (BMS)
- Implementation into the existing BAS concept

Emphasis was placed on simplicity, safety and efficiency. For this reasons the battery swapping station is located near the pool of robots. Designed concept answers general BAS requirements. The logical next step would be research in a field of charging techniques and possibility of implementing more batteries for charging in the charger which has the same size. Further research will be focused on concept simulation and prototype development.

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