



POWER ELECTRONICS IN ARTIFICIAL HEART - BUCKUP BATTERY

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Abstract: The paper is an overview of batteries, devoted for artificial heart that is totally implantable in the body of patient, seen from the power electronics' point of view. The overview is aimed at the battery that could operate like backup battery (inner) one. Then the actual overview, based on block diagram and relevant specification (power (~20W), power losses (~10W), time of charging/discharging (~20min), voltage (~24VDC), lifetime (~one year) etc.) is carried out. The lithium-ion battery appears to be the best candidate as the backup one.

Key Words: power electronics, TI artificial heart, batteries

- Maximum possible discharging current,
- 20 W of rated discharging power,
- 20 min of discharging at rated power and afterwards 20 min of discharging at half of rated power,
- Nominal capacity 0.42 Ah (at 20 W during 0.5 h),
- Number of cycles of charging/discharging - ~1000,
- Operating temperature ~38°C,
- Maximum possible power-to-mass rate (W/kg),
- Maximum possible power-to-volume rate (W/m³),
- Implantable housing - biocompatible.
- It should comply with safety standards,
- It also should comply with EMC standards.

1. MOTIVATION

An artificial heart is still challenge for contemporary medicine, engineering and power electronics in it. Although the first totally implanted artificial heart was implanted in 2001 (AbioCor), there are still a lot problems to be solved and improved. They can be easily recognized when looking at it from the power electronics' point of view one can easily recognize many engineering problems such as contactless/wireless energy transmission by means of transformer, reduction of power loss, especially inside of patient, reduction of the size and weight, reliability, long life of batteries, EMC (EMI in it). Besides, there are the problems associated with transmission signals to and from patient's body. Also the pump and its driving electric motor is the problem for itself.

The paper is devoted to batteries that are the part of power electronic system of artificial heart that is totally implantable.

The aim of this paper is selection the best candidate battery for the system of totally implantable artificial heart.

2. ASSUMPTIONS

The following assumptions concerning inner battery:

- 24 V – rated voltage,
- Minimum possible ESR and inherent inductive reactance,

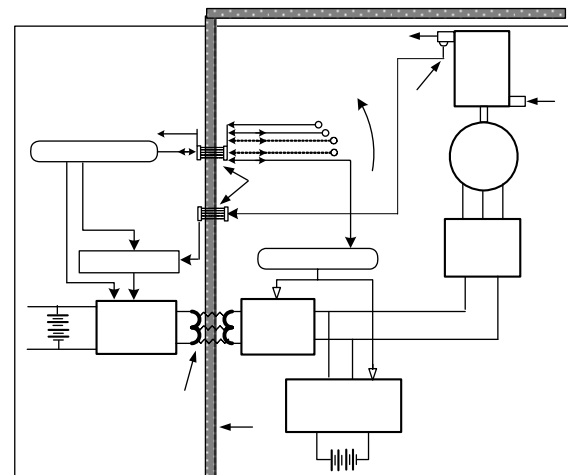


Fig. 1 Backup (Internal) battery in artificial heart system

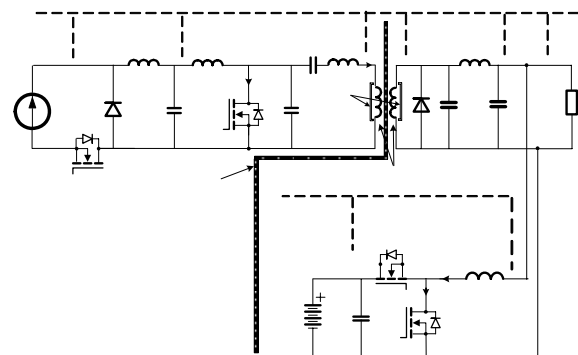


Fig. 2 Details of artificial heart system

3. ARTIFICIAL HEART

The place of battery in the system of artificial heart can be seen in block diagram in Fig. 1 and Fig. 2. In the normal operation called normal mode the main stream of energy is delivered through the skin via high frequency (HF) transformer and synchronous rectifier. Then the energy is transmitted to the pump through DC-AC converter and BLDCM. In normal mode of operation, when internal battery is to be charged the energy is delivered to it via DC-DC converter (buck-boost). The latter is operating in such mode like charger. The second mode of operation is designed, called internal mode of operation. It takes place when energy can not be delivered through the skin. The energy is taken from internal battery and transmitted via two converters, DC-DC and then DC-AC one. The former converter operates in this case like discharger of internal battery that controls the power of discharge process.

The inner part of the system is controlled by internal microprocessor, Intern uP, that is in turn controlled by external microprocessor Extern uP. The operation of the internal part of the system is monitored by measurement of temperature in several points and measurement of pump's flow. The relevant data flows through infrared transmitters. It is possible to control the flow of pump basing on negative feedback using Compensator. The monitoring data is continuously stored (Data acquisition). The whole system is supplied from external battery that is attached to the waist of patient.

In order to have the system has to comply with demands given in section 2. Assumptions.

One of mine concerns is power losses of elements of the system, especially those there put inside of the patient's body. Transformer seems to be the most important. Beside constructional issues the transformer should be compensated for L_{S1} and L_{S2} with capacitors C_1 and C_2 . Such compensation reduces reactive power what reduces power losses.

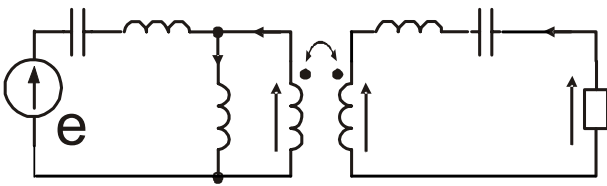


Fig. 3. Equivalent circuit of the transformer

4. OVERVIEW OF BATTERIES SUITABLE FOR OPERATION AS BACKUP BATTERY

The essential information are contained in [1] – [10]. There are following batteries that theoretically could be candidates for backup battery: lead acid, nickel iron, nickel cadmium, nickel metal hydride, nickel zinc, nickel hydrogen, lithium secondary cells, sodium sulphur and other types [1], [6]. Not all of them are suitable to this application. There exists Nickel hydrogen battery [1] that having 40 000 cycles live, used in space technology, operates at 60 atm is not suitable. The work [1] reports

on such battery type operating at 1 atm. Additionally, this battery has relatively low energy density. The highest energy density exhibits lithium batteries but their cycle life is slightly above 1000. It is necessary to notice that even nuclear power batteries were tested in cattle in order to prove its applicability [10]. Nickel-cadmium and nickel metal-hydride batteries also were candidates for some time but because their relatively small energy density 125 Wh/liter and 175 Wh/liter they lose to lithium ion one that has 400 Wh/liter. Nowadays lithium ion batteries having high performance expressed by high energy density (W/liter), high specific energy (W/kg) and high power density (W/kg) is the best candidate for backup battery (backup battery) [3], [7], [8], [9], [10].

Lithium has the lowest specific gravity/mass (053g/cm³) among bulk elements. It has greatest electrochemical potential that gives it possibility to achieve very high performance when used for batteries. Its voltage is 3.6 V and is produced within broad range of capacities, from 500 mAh to 1000 Ah. It is safe for environment.

The small drawback of lithium batteries is its relatively high internal esr. The result of this overview is that the best candidates for back battery is lithium ion one.

It is possible to choose such battery as is presented in [11], e.g. Li/CFx or Li/MnO₂ families, that is fabricated in titanium or stainless steel cases.

The overview results in the conclusion that the best candidate for backup battery (inner battery) is lithium ion one. To make final engineering decision about details of the battery it is necessary make thorough analysis of the whole system of totally implantable artificial heart and FEM analysis in it.

5. CHARACTERIZATION OF CHOSEN BATTERY

The best candidate for inner battery of totally implanted artificial heart that fulfill assumed characteristics is battery manufactured by EaglePicher Medical Powers [11]. It is described as – CONTEGO Series. It is lit Li-Ion type. It has the following parameters: number of charging/discharging cycles 1000 that means ~1.5 of year at 2 charging/discharging per day. Its rated voltage is 3.6 V per cell at 140 mAh of rated current.

Taking these parameters and assumptions into account one can find the following description of the whole battery:

Minimal charging current $I_{\text{char min bat}} =$

$$P_{\text{DC}}/U_{\text{DC}}=20/24=0.833 \text{ A.}$$

Battery capacity at 0.5 hour (for discharging it with $I_{\text{char min bat}}=0.833$) $Q=1.2I_{\text{char min}}*0.5=0.5 \text{ Ah.}$

Number of cells connected in series

$$N_{\text{Bs}}=1.2*U_{\text{DC}}/U_{\text{On}}=1.2*(24/3.6)=8.$$

Number of 8-batteries connected in parallel (at $I_{\text{char}}=140 \text{ mA}$)

$$N_{\text{Bp}}=I_{\text{char min bat}}/I_{\text{char min}}=0.833/0.140=6$$

Power losses ~7 mW.

Dimensions of the whole battery (8 cells in series in one battery x 6 batteries in parallel):

$$h=4*25=100, w=4*15=60\text{mm}, g=6*6.85=42\text{mm}$$

Assuming 10 W of ratek capacity the thickness is reduced to 22 mm. (it means ~240 g)

Such dimensions of the whole battery are acceptable.

6. CHARGING PROCESS

Charging process should be carried out due to voltage-current profile depicted in Fig. 4. It is applied in IC MCP73831/1. Principle of operation of it is described by block diagram in Fig 5.

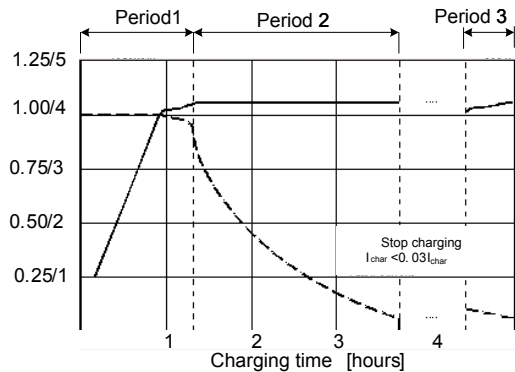


Fig. 4. Charging process [13]

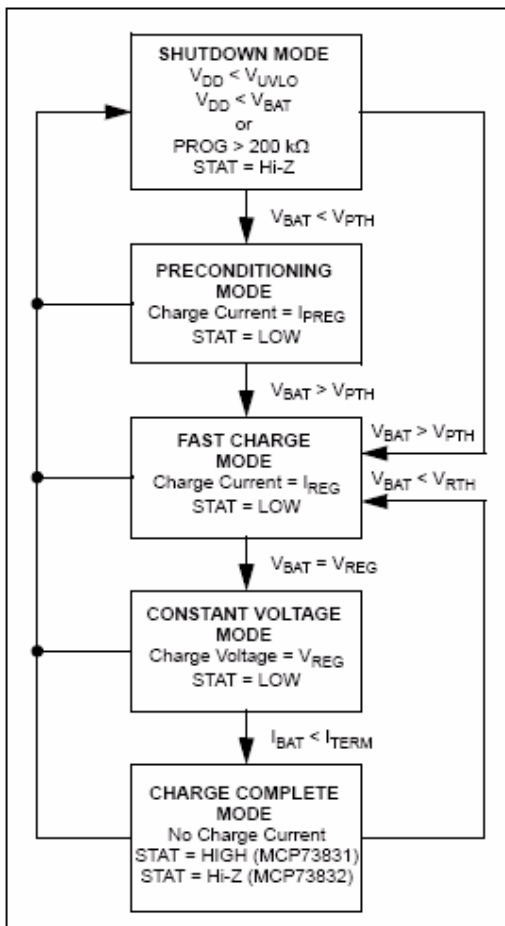


Fig. 5 Block diagram of charger MPC73831/1 [13]

7. CONCLUSIONS

- Overview of the batteries that can be applied to totally implanted artificial heart results in choice of Li-ion type manufactured by EaglePicher Medical Powers.
- Calculation of volume and weight of the battery assembled from EaglePicher cells gives the following results: 100x60x43mm and ~240 b that is acceptable.
- Such battery can operate for 1000 charging / discharging cycle which gives 1.5 year of time between replacements.
- Chosen cell is designed for medical appliances, being biocompatible.
- Continuation of this work is design complete system of charging and discharging of the battery together with DC-DC buck-boost converter, build it and test its parameters and characteristics.

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