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Procedure of Selecting Optimum Capacity and Voltage for an On-Board Electric Power Supply System Accumulators

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Abstract

Objectives: This article aims at discovering possibilities of full use of resources of on-board power supply units against any limitations that arise in operation of robotic systems. **Methods:** Large-scale implementation of mobile robotic systems determines feasibility of more severe requirements to engineering solutions that are specified for the design of such systems. Simulation of an accumulator discharge process with the given supplied power schedule of an electric propulsion system and other on-board systems is an approach to optimizing the electric power supply and electric propulsion systems that is used in this article. **Findings:** An accumulator battery discharge model is proposed based on which the algorithm for calculating the actual battery capacity is developed. The input data for the algorithm is a family of discharge characteristics given in the tabular form and containing the curves $U = f\,(C)$ for some finite set of discharge currents. Optimization criteria for electric propulsion and electric power supply systems are discussed, the relevance of task of accurate calculation of accumulator battery capacity against an alternative schedule of supplied power is justified, key electric power consumers and specifications are provided, and a list of input data to calculate the electric power supply system is made. A block diagram of use efficiency estimation of accumulator batteries is offered. **Applications/Improvements:** The developed algorithm for calculating the actual battery capacity for a given power consumption schedule can be used to select batteries with the lowest possible weight. Application of the proposed methodology for assessing the utilization efficiency of accumulator batteries will improve the mass-dimensional indicators of the developed mobile systems, as well as reduce their cost and power consumption.

Keywords: Accumulator, Electric Power Supply, Electric Propulsion, Optimization, Robot, Resource

1. Introduction

1.1 Introduce the Problem

Mobile robotics became a part of over life just recently. These were individual devices before, not used outside a laboratory and bearing no strict specifications, while we are talking about mass production now, and requirements to efficiency of any applied solutions rose sharply.

Electric power supply and electric propulsion sub-systems that are common to all mobile robotic systems and take a great part of such systems in terms of weight, dimensions and cost, which is decisive for possible cost and energy saving against rational selection of the structure, parameters and components of these sub-systems. Optimum selection of the structure and element base of on-board electric power supply and electric propulsion systems is a major design challenge of robotic systems.

Design and optimization of the above systems must be combined, as long as the electric propulsion system is the major power consumer in mobile platforms, on the one hand, and accumulator batteries take up a great share of weight of such mobile platform, on the other hand.

The following may be used as optimization criteria:

- providing for maximum run with the given limitations to weight and dimensions; and
- providing for minimum weight with the given run.

Moreover, any requirements to providing for battery resources no lower than the required number of charge

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and discharge cycles, which is expressed in a limitation on permissible battery discharge depth and leads to an increase accumulator weight, may be imposed. This limitation is particularly vital in case of robotics operated in remote places, like outer space, where proper battery replacement may pose a problem.

On-board accumulators of the robotic platform may be charged, using an internal combustion engine generator, for remote operations. The criterion of minimum power consumption of the platform as a whole with the given minimum run dominates in these conditions against power supply made difficult. This criterion implies account for any losses that occur not only in secondary power supply, but also in accumulator charge.

Any other optimization criteria may be available for mass production that are determined by such economic factors as prime cost minimization and owning cost minimization. These criteria must be considered collectively or at least together with any of the above criteria. Provided these criteria are considered collectively and with view to ambiguous selection, one must build up a Pareto set for further selection of a certain option by expert opinion method.

1.2 Explore Importance of the Problem

Operating experience shows that accumulator capacity depends on discharge current and it decreases with the current increasing. According to a typical accumulator element discharge specification that is given in figure one, discharge current increase from 1C to 2C leads to capacity decrease (given in ampere-hours) by 15% of the total capacity. Actual element energy will decrease even more, given the decreased voltage. A coarse estimation gives a decrease in the element energy that is available for use by

$$\Delta E=\left(1-\left(1-\frac{U_{1C}-U_{2C}}{U_{1C}}\right)\cdot\left(1-\frac{Q_{1C}-Q_{2C}}{Q_{1C}}\right)\right)= \qquad (1)$$

$$=\left(1-\left(1-\frac{3,6-3,4}{3,6}\right)\cdot\left(1-\frac{0,95-0,75}{0,95}\right)\right)\cdot 100\,\%=21\,\%,$$

where $U_{1C}=3,6$ V and $U_{2C}=3,4$ V - accumulator element voltage values in the central part of discharge specification at discharge current values of 1C and 2C, accordingly; $Q_{1C}=90\,\%$ and $Q_{2C}=75\,\%$ - element capacities at the same current values.

When the requirements to enhanced accumulator resource are placed, this results in an increase in maximum permissible accumulator discharge voltage. According to figure 1, this leads to an additional decrease in the accumulator capacity that is permissible for use. For example, if we limit permissible decrease in accumulator cell voltage to 3.2 V, accumulator capacity will be by 27% lower at discharge current of 2C vs. discharge current of 1C, and energy that is derived from the accumulator will drop even further.

Operation of robotic systems is known for broadly variable and uneven electric power consumption. For example, if we overcome power barriers, supplied power to the electric propulsion system may increase severalfold for a short time and drop close to zero and even be negative in downhill operation. Therefore, our selection of accumulators with view to maximum supplied power is irrational, as long as it leads to an unreasonable increase in weight and dimensions and increase in losses in the electric propulsion system. In this case, the increased accumulator battery weight leads to an increase in all-body and dynamic loads on the electric drive, which requires, in its turn, an increase in drive power and leads to an increase in electric propulsion system weight, and increased electric power consumption by the whole system and an additional increase in accumulator weight, as a result.

As long as electric propulsion system load is static, one should make calculations, using certain averaged diagrammatic work of the robotic system.

Overall, two sub-systems that are given in figure 2: electric propulsion sub-system and useful load, which

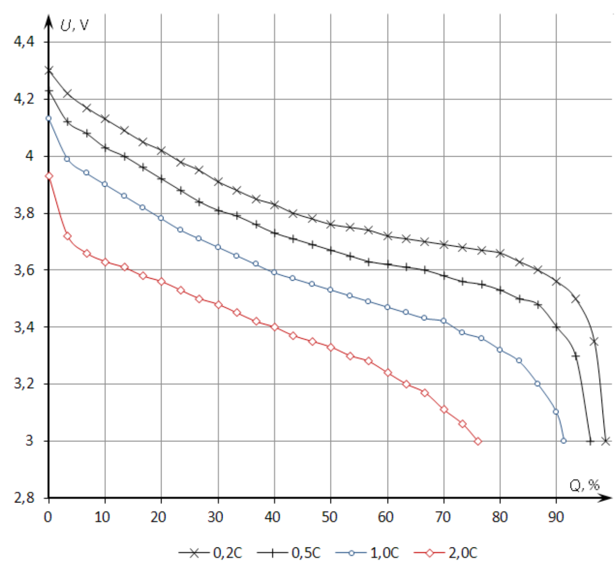

Figure 1. Typical specification Li-ion accumulator discharge.

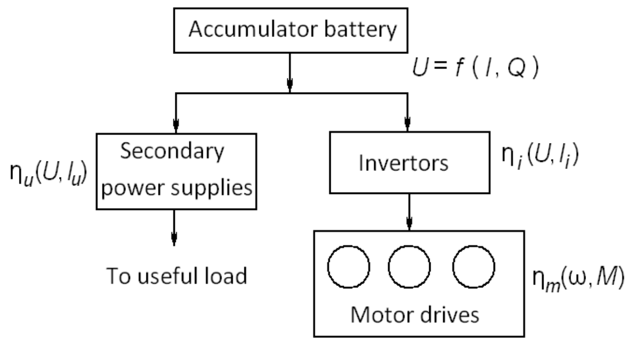

Figure 2. Electric power supply and electric propulsion system layout.

may be represented by arms, transmit equipment etc. installed on the robotic platform, are supplied by the accumulator battery. It is obvious that these sub-systems do not operate completely individually. For example, if the robotic platform is equipped with an arm, cooperation of the arm and the electric propulsion system is extremely difficult in practice, if for no other reason than difficulties that arise from joint control of these sub-systems. On the other hand, operation of navigational and transmission equipment is in no way connected to the electric propulsion system.

Therefore, the following input data must be taken for our calculation:

- estimated speed schedule of the electric propulsion system (number of accelerations and brakes, constant speed movement sections, length of such sections);
- estimated terrain (number and length of downhill and uphill sections, slope of such sections, coefficients of resistance to movement on such sections); and
- estimated current consumption schedule by the useful load, as agreed with the speed schedule.

Selection of the most effective structure and components of the electric power supply and electric propulsion systems, in particular of such parameters as accumulator battery capacity and on-board mains voltage is the ultimate optimization goal. The optimization is reduced to exhaustive search of all possible layouts, efficiency estimation of each layout and selection of the best option. This article is devoted to developing efficiency estimation methods.

1.3 Describe Relevant Scholarship

There are a lot of publications devoted to specifications and efficient use of individual components of electric power systems (accumulators and secondary electric power supplies) and elements of electric propulsion systems (motors and inverters), however, rare attention was generally paid to the optimization task.

Discharge specifications that are provided in catalogs of accumulator manufacturers and dependence of secondary power supply efficiency on load and supply voltage are fundamental for this research. Equations to calculate charge and discharge parameters are given in[1]; however, the ratio of superficial concentration of lithium ions and maximum concentration that may be included in the $FePO_4$ grade is given as the argument of the function to calculate accumulator output voltage. This circumstance makes it difficult to use these equations in practice. Techniques of computational 3D simulation of accumulator operation that are provided in[2] allow for obtaining estimated accumulator charge and discharge parameters. However, they require heavy computational resources and their application to this study is unreasonable. Moreover, they provide slightly overestimated values of the calculated voltage in discharge curves vs. actual values, which may lead to accumulator battery capacity overestimation. Lithium-ion accumulator discharge specification is discussed in[3]. Analytical dependencies of accumulator capacity on discharge current and temperature are given in[4,5]. Heat release processes during accumulator batter charge and discharge are discussed in[6]. Measurement and identification concepts of internal accumulator parameters for intelligence accumulator monitor and control systems in the battery for long-time service life that are discussed in[7] may be applied in various engineering industries, including design of electric power supply systems in mobile robotic systems. The effect of incomplete charge-discharge, which happens in mobile systems, on lead and lithium-ion accumulator battery degradation is studied in[8]. Preference is given to LFP. Techniques of feasibility estimation of application of various accumulator batteries for fixed power installations are discussed in[9]. These techniques may serve as the basis for analyzing efficiency of battery application in mobile systems as well. At the same time, one should bear in mind that battery efficiency reduces against decreased relative energy that is stored in such batteries.

Unfortunately, not many power supply manufacturers provide the necessary data in their catalogs. Radiator selection for DC/DC inverters is discussed in[10]; therefore, dependence curves of efficiency on the ratio of output power P and rated power P_N are provided. An example of such curve for supplies of output voltage from 12 to 60 is are given in figure 3. It should be mentioned that the curves are given in[10] for certain supplies of a certain manufacturer for rated supplied power values. Mornsun[11] provides dependencies of efficiency on load and on supplied power for its inverters.

One may distinguish between the following losses in an electric propulsion system: mechanical losses due to friction in transmission gears and wheel rolling friction, and electric losses in inverters and engines. Mechanical losses arising in case of movement of wheeled vehicles and energy saving possibilities are discussed in[12,13]. Optimization alternatives for routes in difficult terrain are given in[14]. Detailed analysis of losses in inverters of an asynchronous variable-frequency controlled electric drive and asynchronous motors themselves is conducted in[15]. A drive that is based on synchronous motors or collector DC machines is usually installed in small robotic systems. However, despite slight differences in control algorithms, inverter power canal operation with the synchronous motor connected is analogous to that of asynchronous motor. Therefore, the loss analysis that is provided in[15] may be fully used for a synchronous drive as well. Approaches to calculating losses that are given in[15] may be transferred, including fine adjustments, to pulse-width voltage controls of DC collector motors. Loss accounting in a collector and synchronous motor bearing permanent magnets is trivial and presents no difficulties today.[16-18]

1.4 State Hypotheses and Their Correspondence to Research Design

To solve the problem stated in this research, operation of an electric supply power system of a robotic platform is simulated. At the same time, simulation of the useful load and electric propulsion system is simplified, and major attention is given to accumulator battery function simulation. A dependence of supplied current on time is determined in simulation, and residual accumulator discharge value is calculated, using such dependence. This simulation process is repeated for several layout alternatives of electric power supply and electric propulsion systems, and the best option is selected according to one of criteria specified in sub-cl. 1.1.

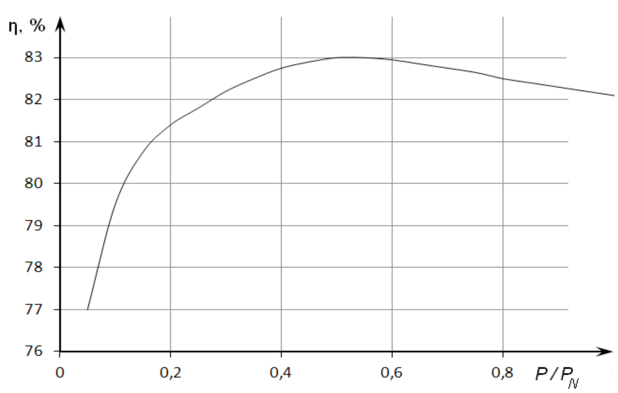

Figure 3. Dependence of secondary power supply efficiency on load power.

The following assumptions are made for accumulator batter simulation:

- loss current that determines a decrease in accumulator capacity depends solely on supplied current from the accumulator itself and does not depend on accumulator charge; and
- accumulator charge is fully spent against a decrease in voltage to minimum permissible value, regardless of discharge current.

These assumptions require experimental verification, which is beyond the scope of this article.

Most manufactures provide efficiency parameters for their power supplies for rated load only. As long as the processes that go on in power supplies are the same, the curve that is given in figure 3 may be scaled to the rated efficiency of the supply and it may be assumed that the efficiency depends on load, according to such curve and as a first approximation.

2. Concept Headings

2.1 General Efficiency Estimation Diagram

It is suggested to estimate the use efficiency of accumulator batteries, using a block diagram that is given in figure 4. This diagram involves an accumulator model that will be developed in our next system, power supply sub-system and electric propulsion sub-system.

The electric propulsion sub-system is provided in the form of a double-circuit subordinated control system and a DC motor. This representation is fit for collector machines and synchronous motors equipped with permanent magnets, if driven by an inverter. Speed values ω_{ref} that were obtained from the estimated speed operating schedule of the electric propulsion system are given at the speed control input. A function of time is used to this effect. Speed and current controls include current and voltage limitations, accordingly, at their outputs. Output

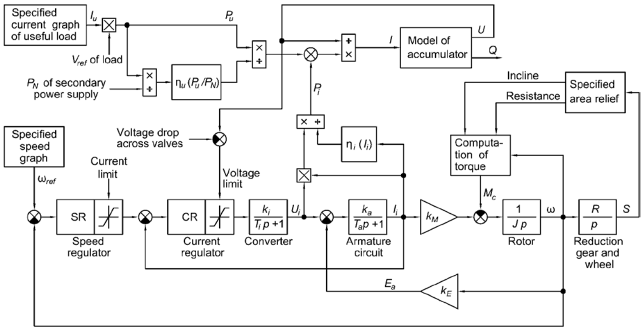

Figure 4. A simplified structure of evaluation model of accumulator batter use efficiency evaluation model.

voltage U_i in the inverter must not exceed accumulator battery voltage E reduced by a voltage drop on open inverter keys. In reality, this voltage limitation may be more severe, if the motor is rated for a voltage lower than voltage of the on-board mains at fully charged accumulators. Parameter J in Rotor link is a moment of inertia reduced to a motor shaft of all propelled weights, and parameter R in Reduction gear and wheel is total reduction radius, comprising wheel radius and gear reduction ratio. Path S that is obtained, following integration, is a path of the robotic platform and it is transferred to the unit that calculates current slope and resistance to movement, based on the expected terrain. Momentum on the motor shaft is calculated, using the above data. Inverter efficiency and supplied power P_i from the on-board mains to the electric propulsion system is determined, using motor voltage and current values.

The useful load is supplied by direct stabilized voltage V_{ref}; therefore, given current schedule determines essentially supplied power schedule.

Accumulator current output is calculated, using supplied power value. The accumulator model calculates residual charge and voltage, using this current value.

3. Results

3.1 Developing an Accumulator Battery Functioning Model

Currently, accumulator discharge specifications are provided as voltage-capacity or voltage-time in operation curves. At the same time, several curves for various discharge currents are provided. Accumulator capacity decreases in a non-linear way with current increasing. For discharge parameters that are given in figure 1, an approximate dependence of capacity on discharge current is

$$Q(I) = -1,82 \cdot I^3 + 2,7 \cdot I^2 - 10,0 \cdot I + 100, \qquad (2)$$

where Q — accumulator capacity [% of rated capacity]; I — discharge current in units of rated capacity. The corresponding diagram is given in Figure 5.

As long as mobile systems operate at variable loads, the intermediate task is determining accumulator capacity against the given load cycle.

Charge Q^* is imparted to the accumulator during charging. When the charge discharges, one part of such charge Q_l is transferred to the load, and the other part Q_r is used for heat generation. For discharging with certain fixed current $i_{l1:}$

$$dQ^* = dQ_{l1} + dQ_{r1} = i_{l1} \cdot dt + d(i_{r1} \cdot t). \qquad (3)$$

Generally, current loss value is i_{r1} and may depend on time t and accumulator charge Q^*. However, due to the fact that no data are provided in the literature, let us assume that i_{r1} depends exclusively on current i_{l1}, then

$$dQ^* = i_{l1} \cdot dt + i_{r1}(i_{l1}) \cdot dt. \qquad (4)$$

For full discharge cycle with fixed current i_{l1} and $i_{l:}$

$$Q^* = Q_{l1} + Q_{r1} = i_{l1} \cdot T_1 + i_{r1} \cdot T_1, \qquad (5)$$
$$Q^* = Q_{l2} + Q_{r2} = i_{l2} \cdot T_2 + i_{r2} \cdot T_2.$$

Let us now consider measures that may be determined from the diagrams that are similar to those presented in figure 1. Accumulator run time until full discharge is determined according to the equations (see Figure 6)

$$T_1 = \frac{Q_{l1}}{i_{l1}}; \qquad T_2 = \frac{Q_{l2}}{i_{l2}}. \qquad (6)$$

Moreover, one can determine current loss ratio between discharge curves. According to equations (5):

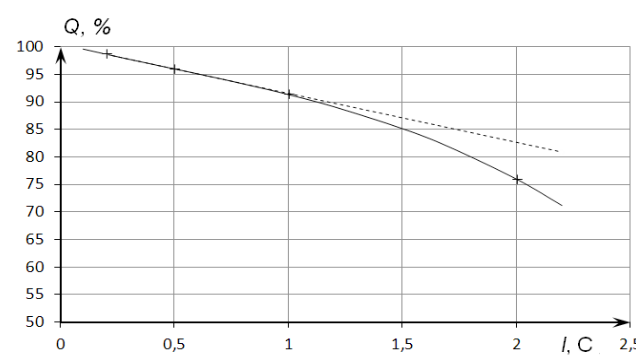

Figure 5. Discharge currency and accumulator capacity reduction diagram.

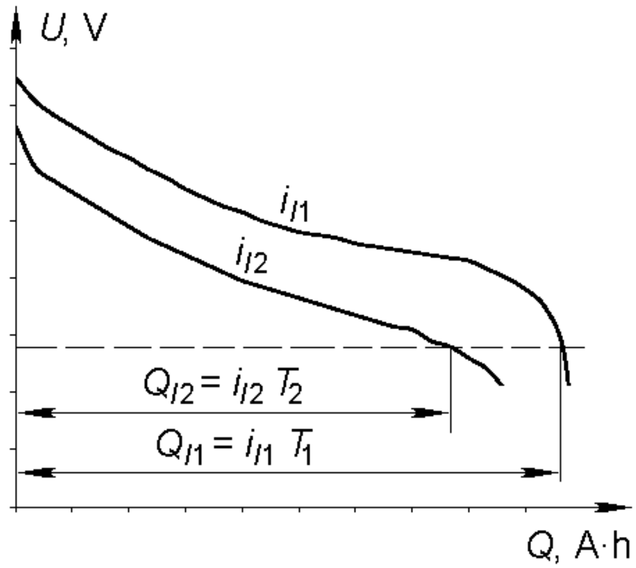

Figure 6. Graphic determination of accumulator run-time.

$$i_{l1} \cdot T_1 + i_{r1} \cdot T_1 = Q^* = i_{l2} \cdot T_2 + i_{r2} \cdot T_2, \tag{7}$$

or

$$\left(i_{l1} \cdot T_1 - i_{l2} \cdot T_2\right) + i_{r1} \cdot T_1 = i_{r2} \cdot T_2. \tag{8}$$

The expression in brackets can be determined directly from the diagram. Loss current i_{r2} is connected to loss current i_{r1} in the following ratio:

$$i_{r2} = \frac{Q_{l1} - Q_{l2}}{T_2} + i_{r1} \cdot \frac{T_1}{T_2}. \tag{9}$$

A difference between loss currents is important for estimating accumulator battery capacity rather than absolute loss current values. Therefore, it appears reasonable to select one of discharge curves to be the basic one and assume loss current i_{lB} equals to zero in such curve. In this case, equation (9) is:

$$i_{r2} = \frac{Q_{lB} - Q_{l2}}{T_2}. \tag{10}$$

For any curves that are located lower loss current will be positive and for any curves located higher loss current will be negative. In relation to the latter, the loss current will not reduce but sort of increase accumulator capacity vs. basic capacity Q_{lB}.

According to equations (4), (5) and (10) one can easily obtain capacity reduction ΔQ_{lB} for discharge of the given current i_{l2} during time Δt

$$\Delta Q_{lB} = i_{l2} \cdot \Delta t - \frac{Q_{lB} - Q_{l2}}{T_2} \cdot \Delta t, \tag{11}$$

or, after inserting (6) and transforming

$$\Delta Q_{lB} = \frac{Q_{lB}}{Q_{l2}} \cdot i_{l2} \cdot \Delta t. \tag{12}$$

Accumulator capacity reduction measure that is reduced to the basic value is obtained for discharge current i_l

$$\Delta Q(t) = \int_0^t \frac{Q_{lB}}{Q_l(i_l(t))} \cdot i_l(t)dt. \tag{13}$$

Total capacity Q_l for the given discharge current i_l should be calculated, using interpolating Lagrange polynomial.

Let us determine accumulator run time t_{rmn} for the given current i_{l2}, following accumulator discharge by ΔQ A·h. The residual accumulator charge is determined by a difference Q_{lB} – ΔQ(t). As long as this charge must be spent up to full accumulator discharge, then in accordance with (12)

$$(Q_{lB} - \Delta Q) = \frac{Q_{lB}}{Q_{l2}} \cdot i_{l2} t_{rmn}, \tag{14}$$

and

$$t_{rmn}(i_{l2}) = \frac{Q_{l2}(i_{l2})}{i_{l2}} \cdot \left(1 - \frac{\Delta Q}{Q_{lB}}\right). \tag{15}$$

Let us now consider calculation of accumulator output voltage. Accumulator battery discharge curves that are the same as presented in figure 1 may be entered into the PC or presented as an analytical expression, or table. In the computerized accumulator model that is discussed here, the second option was used, and each curve for fixed discharge current i_{lk}, k=1…n was presented in the form of discharge-voltage pair (ΔQ_i; U). Where discharge current corresponds to one of the given curves, basic discharge ΔQ must be converted into accumulator charge at the given load $\Delta Q_l = \Delta Q \cdot \frac{Q_l}{Q_{lB}}$, in order to determine voltage. Then, values that are closest to the given discharge are selected from the table, and linear interpolation of corresponding voltage values is done. However, discharge current is far more probable to be between the given values. In this case, calculation algorithm is as follows:

- according to accumulator discharge degree ΔQ, accumulator discharge degrees are determined for the rest fixed currents i_{lk}

$$\Delta Q_{lk} = Q_{lk} \cdot \frac{\Delta Q}{Q_{lB}}, \qquad k = 1, 2, ..., n, \qquad (16)$$

- for each value ΔQ_{lk} obtained by means of linear interpolation, voltages $U_{l1}\ldots U_{ln}$ are determined on corresponding discharge curves; and
- using the interpolating Lagrange polynomial, unknown voltage U is determined, according to voltages $U_{l1}\ldots U_{ln}$ and discharge currents $I_{l1}\ldots I_{ln}$, I_l.

4. Discussion

A program to simulate accumulator operation was developed to make the above calculations. Tables that describe discharge parameters, degree of accumulator discharge at the previous calculation cycle, and current supplied by the accumulators, and period of time elapsed from the previous calculation step serve as inputs. Accumulator output voltage, degree of discharge at the current calculation cycle and estimated run time for the given supplied current are outputs.

This program may be used to build up discharge parameters for any currents that are different than those presented in accumulator specifications. An example of discharge specification for the current of 1.75C that was obtained by means of interpolation from the parameters for discharge 0,2C, 0,5C 1C and 2C, using this program, is given in Figure 7.

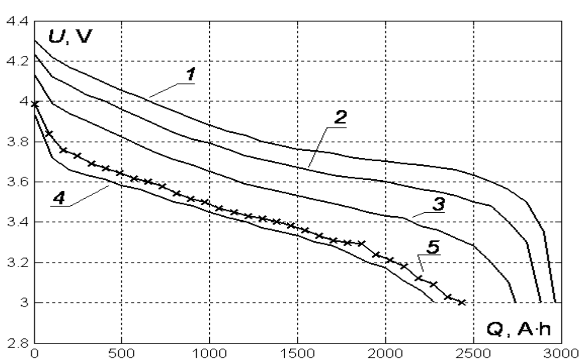

Figure 7. Accumulator discharge specification: *1*, *2*, *3*, and *4* — given for discharge current of 0.2, 0.5C, 1.0C and 2.0 C; and *5* — calculated value, using application given in Annex 1 for current of 1.75C.

Unlike battery capacity calculation methods set out in[4,5], the proposed algorithm allows estimating capacity at an alternating schedule of power consumption. The proposed calculation algorithm uses experimental discharge characteristics and does not require hard-to-get data on which the calculation[1] is based. Interpolation methods applied in the algorithm require much lower computational efforts compared to those used in [2] by the method of three-dimensional modeling, based on the solution of partial differential systems. In addition, unlike other techniques, this algorithm is not tied to a particular battery type and can be used with any type for which the family of discharge characteristics is obtained.

5. Conclusion

It is shown that doubling the battery load current results in reduction of the available energy by 21%. Overestimation of the battery capacity leads to the increase in the mass of the robotic system as a whole, and to the increase in energy consumption by the electric propulsion system. Due to the fact that the battery current consumption by the robotic systems is significantly uneven, the article sets the task of optimizing power supply and electric propulsion systems.

For solving this task mathematical description of accumulator battery operation has been derived. The dependence of accumulator capacity on discharge current is non-linear and is accounted for integrating current values that are reduced to the basic discharge conditions.

A program to calculate output voltage and residual accumulator capacity with the given supplied current that uses this description has been developed as a result of this research. Tables describing the discharge characteristics are the initial data for calculations performed by this program. Calculations of the battery output voltage and the remaining battery charge are made based on the value of the consumed current and remaining battery charge using a linear interpolation method and Lagrange polynomials. The correctness of the algorithm is verified by constructing the discharge characteristics, not specified in the tables.

This program was used as a basis for the structural model layout that has been offered here and is designed to estimate use efficiency of accumulator batteries. To determine instantaneous supplied power, estimated schedules of current used by the useful load, diagrammatic work of the electric propulsion system and terrain are applied, which makes comprehensive study of key factors of accumulator battery operation possible.

Future work will be aimed at refining the losses in mechanical transmissions and the electric channel of the electric drive.

Also in the future it is expected to make descriptions of the expected schedules of current consumption by robot payload and the expected terrain, and to use the developed methodology for the analysis of real-world projects.

Simulation of accumulator battery operation has not been discussed in any other publications; therefore, two hypotheses were given in development of this model:

- loss current depends exclusively on supplied current and does not depend on accumulator charge; and
- accumulator charge is spent completely, if the voltage drops to minimum permissible value.

Corresponding experimental studies are suggested to further determine the extent to which such hypotheses may be applied in the given range of variation of accumulator parameters (discharge current and capacity) and clarify models that are provided in this articles, based on the results of such studies.

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7. References

1. Pal RD, Paul AKR. Charge-discharge studies of lithium-ion batteries. 2015. Proceedings of the 2015 COMSOL Conference in Pune. Available from: https://www.comsol.com/paper/charge-discharge-studies-of-lithium-iron-phosphate-batteries-30271. Dates accessed: 09/08/2016.
2. Vyroubal P, Kazda T, Maxa J, Vondrak J, Sedlarikova M, Tichy L, Cipin R. 3D Modelling and study of electrochemical characteristics and thermal stability of commercial accumulator by simulation methods. International Journal of Electrochemical Science. 2016 May; 3:1810–2512.
3. Klimenko GK, Sorokin MI. Studying power specification of special-purpose accumulators. Engineering Journal: Science and Innovations. E-technical Periodical. 2014; 2(26). Doi: 10.18698/2308-6033-2014-2-1204.
4. Galushkin NE, Yazvinskaya NN, Galushkin DN. Generalized analytical model for capacity evaluation of automotive-grade lithium batteries. Journal of the Electrochemical Society. 2015 Jan; 162(3):A308–14. Doi: 10.1149/2.0311503jes.
5. Galushkin NE, Yazvinskaya NN, Galushkina IA. Analyzing the use of empirical correlations for capacity evaluation of high-rate discharge nickel-cadmium batteries by SAFT. Fundamental Research. 2012; 11-5:1180–4. ISSN 1812–7339.
6. Klimenko GK, Liapin AA, Marakhtanov MK. Studying thermal state of an accumulator in a work cycle. Engineering Journal: Science and Innovations. E-technical Periodical. 2013; 10(22). Doi: 10.18698/2308-6033-2013-10-1030.
7. Sedov AV, Onyshko DA, Lipkin MS. Physical and mathematical design principles of intelligence control devices of autonomous accumulator power supplies. Fundamental Research. 2015; 12-6:1134–8.
8. Krieger EM, Cannarella J, Arnold CB. A comparison of lead-acid and lithium-based battery behavior and capacity fade in off-grid renewable charging applications. Energy. 2013; 60(C):492–500. Available from: http://EconPapers.repec.org/RePEc:eee:energy:v:60:y:2013:i:c:p:492-500. Dates accessed: 09/08/2016. ISSN: 0360-5442.
9. DiOrio N, Dobos A, Janzou S. Economic analysis case studies of battery energy storage with SAM. National Renewable Energy Laboratory: Denver, CO, USA. 2015.
10. Zatulov S, Premiakov S. 20 to 12000 W AC/DC and DC/DC power modules. Available from: http://www.aeip.ru/images/Articles/article05.pdf. Dates accessed: 09/08/2016.
11. Converter URB1D_LD-15W & URB1D_LD-20W Series DC/DC. Mornsun Product Catalogue. 2016. Available from: http://www.mornsun-power.com/uploads/pdf/URB1D_LD-20W.pdf.
12. Schwickart T, Voos H, Hadji-Minaglou J-R, Darouach M. A fast model-predictive speed controller for minimised charge consumption of electric vehicles. Asian Journal of Control. 2016 Jan; 18(1):133–49. Doi: 10.1002/asjc.1251.
13. Yan Q, Zhang B, Kezunovic M. Optimization of electric vehicle movement for efficient energy consumption. North American Power Symposium (NAPS). 2014 Sep 7-9. Doi: 10.1109/NAPS.2014.6965467.
14. Novak D, Pavlovkin J, Volf J, Novak V. Optimization of vehicles' trajectories by means of interpolation and approximation methods. Agronomy Research. 2016; 14(3):862–72. Available from: http://agronomy.emu.ee/wp-content/uploads/2016/05/Vol14-_nr3_Novak.pdf#abstract-4315.
15. Braslavskii IY. Energy-saving asynchronous electric drive: a textbook for college students. Academy Publishing House: Moscow. 2004.

16. Rajan N, Kumar AG. A Power Quality Survey on a 22 kV Electrical Distribution System of a Technical Institution as per Standards. IJST. 2016; 9(30). Doi: 10.17485/ijst/2016/v9i30/99034.
17. Chandrasekar Rao TS, Geetha K. Categories, Standards and Recent Trends in Wireless Power Transfer: A Survey. IJST. 2016; 9(20). Doi: 10.17485/ijst/2016/v9i20/91041.
18. Kolanchinathan VP, Kumar GS. Design and Implementation of the Combinational Circuits Testing using Accumulator based BIST to Reduce Delay, Power Consumption and Area. Indian Journal of Science and Technology. 2016; 9(16).

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