Criterion for Determining the Period of Energetically Safe Flight of Unmanned Aerial Vehicles

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Abstract— **The aim of this work was to develop a criterion for determining the period of energetically safe flight of unmanned aerial vehicles (UAV) for various regimes of accumulator operation. When a lithium-polymer accumulator battery (LPAB) is discharged by half or to one fourth of the discharge current maximum, the period of its operation increases (which is logically understandable), but the dependence with the maximum value of LPAB temperature is kept for all intense regimes, the value of this temperature maximum being decreased with decreasing the discharged current. The operation period is decreased, respectively. However, in "soft" operation regimes, which correspond to 1/3 or 1/6 of the maximum load, heating the accumulator is practically absent.**

The maximum rate of temperature changes in various regimes of accumulator operation can be chosen as a criterion of the signal for making a decision "to return home" or to connect with a stand-by accumulator.

The performed investigations with various accumulators of the same type enabled us to ascertain that every accumulator has its individual internal resistance and capacity. Therefore, temperature features of accumulator discharge are recommended to be determined directly after acquiring the accumulator and periodically before flights (in accord with its operation regime). Results of these tests should be registered in its certificate or in the LPAB running log.

Keywords— thermal imager; non-destructive testing; lithium-polymer accumulator battery; unmanned aerial vehicle

I. Introduction

The most widely used now types of accumulators in unmanned aerial vehicles (UAV) are lithium-polymer accumulator batteries (LPABs) [1 – 4]. In accord with their features, these accumulators deserved the titles of the most whimsical, dangerous and short-lived, but despite all these deficiencies, application of these accumulators in aircraft modeling grows very quickly. It can be explained by their unsurpassed index of specific energy (per mass unity) and ability to sustain high discharge currents. At the same time, the absence of liquid electrolyte makes these accumulator current sources more safety in operation than lithium-ion accumulators of previous generations. Therefore, in the models with power electric facilities these accumulators practically have no competitors yet.

Now, in the most cases, testing the electric discharge rate of the accumulator battery (AB) used as a power supply in UAV is not realized in general.

Currently, the main part of drone producers practices the so-called "flights with a fixed time", i.e., the method to test the LPAB discharge, which implies the knowledge of certified data for the discharge time of this battery [5,6]. Knowing this value, operators that service this UAV can plan the respective time of flight, which is set to be lower than the time of battery discharge. And if taking into account the influence of ambient air factors (contrary or flank wind, atmospheric precipitations and so on) that are difficult to predict, it results in enhanced consumption of energy and, consequently, in faster battery discharge. Therefore, the time of flight should be shortened some more. All these measures are reasonable, since the battery discharge lower than the permissible level means lockup of electric motors and, respectively, loss of traction, which leads to loss of UAV with a great fraction of probability.

A serious problem arises in the cases when weather conditions change abruptly. Then the accumulator battery sharply loses the charge level, and UAV will not be able to complete its task and can be destroyed. It involves not only ecological and economical losses, but also loss of important information, especially in wartime. Another side of this problem is as follows: when the accumulator is discharged beyond limit or permanently discharged not entirely, it loses its properties, and its operation time is considerably reduced.

An alternative approach to provide the electric energy amount necessary to perform the flight task is reservation, i.e., mounting several additional batteries aboard. This way enables to prevent UAV loss, since the full discharge of one battery causes automatic connection to the second, third and so on batteries reserved. The deficiency of this approach is inevitable decrease in the mass of useful load in this UAV, which shorten its consumer performances, since using just these flying vehicles for carrying out the specific tasks of customer is eco In the work [5], the authors determined that LPABs are heated when using them in an intense operation regime, but after some period temperature of the battery is decreased. It means that the respective plot for this dependence has its maximum, which provides a principal possibility to determine the moment for returning “home”. In this work, the authors performed thermal vision investigations of LPAB discharge in the regimes corresponding to the following levels of discharge current: maximum, 5/6, 2/3, 1/2, 1/3, 1/6. These experiments enabled us to ascertain that for this row of current values the operation period is respectively increased. In all the intense regimes, the value of temperature maximum is lowered with the discharge current, and the time of operation is accordingly increased. However, in “soft” regimes that correspond to 1/3 or 1/6 of the maximum load, heating the accumulator is practically absent.

The authors offer to determine the safe period up to the command “home” by measuring the maximum velocity of heating the accumulator. Moreover, as it was ascertained earlier, every LPAB has its individual performances and discharge time, which, first of all, is related with its internal resistance. Therefore, temperature features of the accumulator discharge are recommended to be tested directly after acquiring it and periodically before the flights (with account of the operation intensity). The results of testing should be registered in the accumulator technical certificate or special LPAB operation log.

II. SETTING THE PROBLEM

Modern transport system use rechargeable autonomous power supplies (RAPS) – accumulators. For small-sized UAV, testing and diagnosing the accumulator state are of special topicality, because these UAV are widely used now in monitoring of the ambient medium and in other directions of social activity. If the accumulator is discharged, UAV drops and can be destructed. Therefore, it is very important to preliminary diagnose it and to test the state of its residual capacity for making the decision about UAV safe returning “home”.

During discharge of LPAB and carrying out a useful work, the accumulated in it chemical energy is transformed into the electrical one, but not in the total amount, because some small fraction of it is transformed into the thermal form (as caused by losses in the internal resistance).

The decisive factor for all LPAB is not only their portability (small size and mass) but high reliability and long operation time, as well.

The topical problem for UAV that are supplied from LPAB during their flight is to determine the criterion for making the decision of providing safe returning “home” this aerial vehicle.

The aim of this work was to develop the criterion for determining the period of LPAB energetically safe flight in various regimes of accumulator operation.

III. IDEA AND THE METHOD FOR INVESTIGATIONS

The idea to develop a criterion for determining the state of discharge of lithium-polymer accumulators was based on the fact that electrochemical processes in them are accompanied by thermal phenomena, which should depend on operation regimes. Therefore, it was decided to use a thermal imager for ascertaining the influence of LPAB discharge operation regimes on the accumulator temperature. And it was the base for attaining the set aim.

It was previously ascertained [7] that in an intense operation regime LPAB is heated but after some period of operation it is cooled. The respective temperature plot has its maximum, which gives the principal possibility to determine the moment for returning “home”.

In this work, the method for investigations consisted of thermal imaging measurements per definite intervals (1 min) in LPAB regimes corresponding to the following levels of discharge current: maximum and 5/6, 2/3, 1/2, 1/3, 1/6 fractions of this maximum value.

IV. OBJECTS AND RESULTS OF EXPERIMENTAL INVESTIGATIONS

As an object for testing, we chose the lithium-polymer battery (produced by the firm “Zippy compact”) possessing the capacity 1500 mAh.

To provide the necessary real load for used LPAB in specific investigations of its behavior during testing in the electric circuit of our breadboard model (like to that used in [7]), we also applied the thermal imager EasIR-4 (Tabl. 1).

TABLE I. TECHNICAL SPECIFICATION OF EASIR-4

Parameter	Value
Detector type	Microbolometer UFPA (160x120 pixels, 25 μm)
Spectral range	8-14 μm
Field of View	20.6°x15.5°
Focus	11 mm
Thermal Sensitivity	≤0.1°C
Operating Temperature	-10°C ~ +40°C

With account of the results obtained in the course of investigations, we plotted the dependences of temperature on the discharge time for the following regimes of accumulator operation corresponding to the discharge current maximum and 5/6, 2/3, 1/2, 1/3, 1/6 fractions of it.

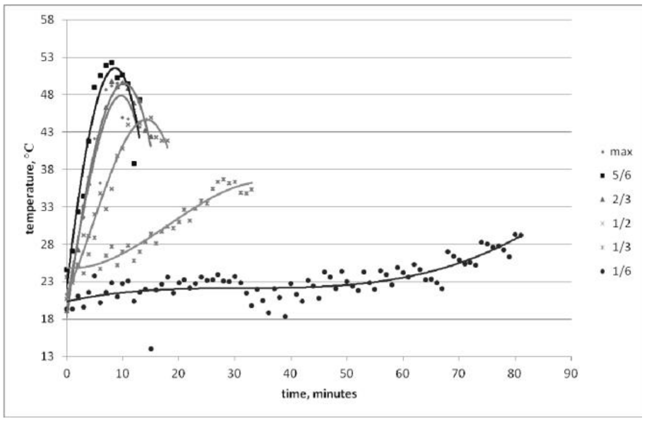

Fig. 1. Time dependence for the accumulator temperature on the discharge intensity.

As can be seen from these plots, two ranges of accumulator operation can be separated: i) the intense one (from the maximum discharge current down to ½ of its level) and ii) the "soft" one (1/3 and 1/6 of the maximum level). In the first range, with a decreased discharge current the temperature maximum is practically observed at the end of accumulator operation, and its value decreases. The operation period is respectively prolonged. Consequently, if the control will be based on such temperature dependences, determining the criterion for making a decision of returning "home" is possible at earlier stages of accumulator operation. As this criterion, we chose the velocity of temperature growth.

Plotted also were the time dependences for respective velocities of accumulator heating, in accord with the data of Fig. 1. These dependences can be seen in Fig. 2.

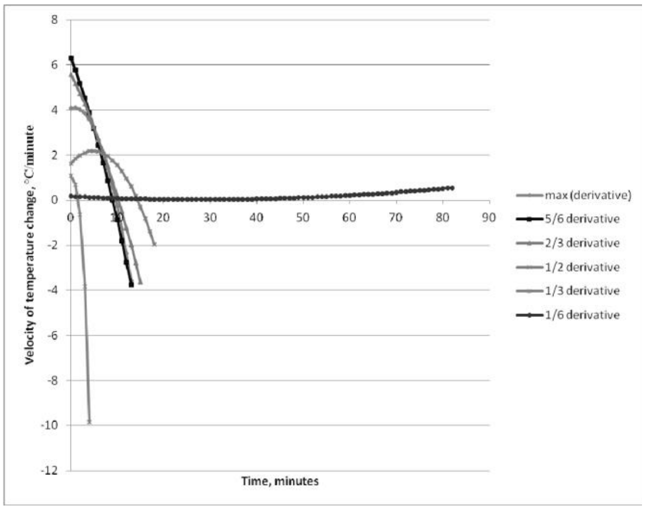

Fig. 2. Plot of dependences for the velocity of accumulator temperature changes on the discharge intensity.

It follows from Fig. 2 that the maximum of velocity for the observed temperature changes in different operation regimes can be really chosen as a criterion to make the decision of "returning home". In the intense operation regimes, this criterion has the values within the range 6.32 down to 2.188 °C/min for the chosen accumulator. Even in these cases, the accumulator keeps a sufficient capacity for guaranteed returning "home" of UAV, or the latter can be connected to the stand-by accumulator. These values of the chosen criterion correspond to risky operation state. It is desirable to provide service in the "soft" regime that corresponds to 1/3…1/6 of the maximum discharge current. Here, the value of chosen criterion can become zero or even negative (cooling by ambient air), and the duration of flight is 3 to 8 times increased.

Besides, our investigations performed for different accumulators of the same type enabled us to determine that every accumulator has its individual internal resistance and capacity. Therefore, the temperature features of accumulator discharge should be ascertained directly after acquiring it and periodically before flights (in accordance with the intensity of operation). The results of testing must be registered in the LPAB technical certificate or operation log.

V. Conclusions

When using the LPAB discharge regimes with the halved maximum of discharge current (or choosing one fourth of this maximum), the accumulator operation time increases, but the dependence with the maximum value of LPAB temperature is kept in all the intense regimes, the value of temperature maximum being decreased with decreasing the discharged current. The operation period is respectively increased. However, in the "soft" regimes that correspond to 1/3 or 1/6 of the maximum load, heating the accumulator is practically absent.

The maximum of velocity inherent to accumulator temperature changes in different operation regimes can be chosen as a criterion to make a decision about returning "home" or to connect up the stand-by accumulator.

The performed investigations with various accumulators of the same type enabled us to ascertain that every accumulator has its individual internal resistance and capacity. Therefore, it is recommended to test temperature features of accumulator discharge directly after acquiring it and periodically before flights (with account of accumulator operation intensity).

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