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THE DETERMINATION OF THEORETICALL ELECTRICITY CONSUMPTION WHEN ASSEMBLING FIXED THREADED JOINTS WITH SCREWDRIVER USING PULSE-WIDTH MODULATOR

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ABSTRACT
In given article the nut driver's electric power consumption studies depending on the corresponding fixed threaded joint's assembly time are made. So far there are no recommendations from the tool manufactures for nut driver's optimal operating modes (the conclusion is made based on the attached instructions which provide instrument manufacturers), when evaluating this aspect taking into account the electrical power consumption and assembly time for different types of fixed threaded joints (wood, metal, plastic, etc.) and also taking into account obtainable tightening moments. In the examined literature sources which deal with the opportunities concerning the optimization of the automated assembly processes of fixed threaded joints, not enough attention is paid to the reduction of the instrument's energy consumption which is one of the main tasks in the industrial process because it directly impacts production costs.
Keywords: fixed threaded joints, nutdriver, electric power, power consumption calculations, assembly time, optimization, optimal operating modes.

1. INTRODUCTION
In nowaday's automated manufacturing the question concerning electric power consumption reduction is of great interest, and it leaves its impact on the final product cost. One of the options for reducing consumption of electric power is an efficient nut driver – screwdriver's use.
In the literature [2, 3, 4] is described the power estimation addiction from the beginning of speed and load torque, but there is no information about the energy dependence from the initial set speed. This is due to the fact that the electric motor is usually used at a constant or slowly changing mode. Using an electric motor in short-term regimes, it is needed to calculate power for each mode separately. The engine parameters are examined only in the range that they can achieve and it is not considered possibilities to extend this range.
Knowing what power the electric motor develops and each regime's time it is possible to determine the electric power consumption. Fixed threaded joint's assembly time consists of a rotor head's run-time, screwing time, tightening time and reaction time till the start button is released (ratchet mechanism's operating mode).
In the literature sources [5] are given the run-time and acceleration time formulas, but the impact on overall power consumption depending on this time is not viewed. This is due to the fact that the

electric motor is usually operated several tenths of minutes, minutes or even hours and on the total energy consumption's background acceleration time impact is very small. By running the nut driver often with large initial set speed for a short period of time until a few seconds, the run-time energy consumption can take up to 80% of total electric power consumption throughout all opearting period [1].
Estimating the electric power consumption, it will be calculated in 3 stages for the time period when:

1) the motor's run-out takes place,
2) screwing with constant initial rotations takes place,
3) fastening is completed but the run button is not released yet.

The fastening period will not be taken into account provided that it is too small in comparison to the overall assembly period and has hardly any effect on the final result.
The equivalent circuit of the equipment consists of the accumulator's battery, whose electromotive force of voltage U_{BAT}, inner resistance R_{BATT} of the accumulator's battery, resistor R_E where the voltage for determination of the electric power is measured, transistor's resistance R_D, rotor coil resistance of the motor R_R and the comparator's resistance R_{COMP}, which is equal to zero at the run time, inductance of the motor's rotor coil L, which is not taken into account in the calculations, acting in the opposite directions of the electric current flow and its value E is proportional to the motor's rotations.
In order to calculate the energy consumption during the run-out period, first of all it is necessary to determine the current intensity. The run-out's initial current value I_{STALL} is provided in the motor's data sheet. The current intensity I_{START2} at the end of the run-out can be calculated according to the formula (1):

$$I_{START2} = \frac{U_{BAT} - E}{R_{BATT} + R_E + R_R + R_{COMP} + R_D}. \qquad (1)$$

The electromotive force E is proportional to the motor's rotations n. It can be calculated according to the formula (2):

$$E = \frac{n}{k_n}. \qquad (2)$$

where: k_n – constant of electric motor;
n – revolutions per minute of a rotor head.
Now it is possible to calculate the normal current I_{START_VID} during the run-out period. Having assumed that the current decreases linearly during the run-out period, it can be calculated according to the formula (3):

$$I_{START\_VID} = \frac{I_{STALL} + I_{START2}}{2}. \qquad (3)$$

Being aware of the current value, it is possible to calculate the power P_1 developed during the run-out period according to the formula (4).

$$P_1 = U \cdot I = I_{START\_VID} \cdot (U_{BAT} - I_{START\_VID} \cdot R_{BATT}). \qquad (4)$$

Every accumulator's battery has inner resistance, on which the voltage drop, that is proportional to the current, occurs. It should be taken into account when calculating the power provided that the battery's voltage can drop in half or even more with large consumable electric power that would have a large impact on the final result, not considering the correct voltage value.
Battery internal resistance R_{BAT} can be determined by the formula (5), firstly measuring battery voltage without load U_0, then it is necessary to connect the load and measure the battery voltage U_{sl} and consumed current $I_{sl.}$

$$R_{BAT} = \frac{U_0 - U_{sl}}{I_{sl}}. \tag{5}$$

During the screwing period with a constant rate, when the pulse-width modulator is in operation, the pulse range is equal with the I_{START2} value and it remains unchanged until the fastening period. In order to calculate the normal current value, the fill coefficient D should be known. It can be determined according to the formula (6):

$$D = \frac{\tau}{T}. \tag{6}$$

where: τ – pulse-width,
T – pulse recurrence period.
τ and T can be determined with an Oscillograph.
The normal current value I_{PULSE_AV} in the pulse mode can be calculated according to the formula (7):

$$I_{PULSE\_AV} = I_{START2} \cdot D. \tag{7}$$

Then the power P_2 during the screwing period at a constant rate can be established according to the following formula (8):

$$P_2 = I_{PULSE\_AV} \cdot (U_{BAT} - I_{START2} \cdot R_{BATT}). \tag{8}$$

To calculate the power P_3 during the reaction period, first of all it is necessary to calculate the speed until which the motor's rotations n_{SL} decreased (9), changing the electric current value I_3.

$$n_{SL} = k_n \cdot (E - \frac{R_R M}{k_m}). \tag{9}$$

where: k_m – moment constant,
M – moment, which loads the electric motor (mNm).
The moment constant k_m is provided in the motor's data sheet. Taking into account that there are transmission gear-wheels between the motor and rotor head, the momentum M, which works on the motor, can be calculated according to the formula (10):

$$M = \frac{M_{ROT}}{A \cdot eff}. \tag{10}$$

where: M_{ROT} – momentum, working on the rotor head (mNm),
A – ratio between rotations of the electric motor and rotor head,
eff – efficiency of transmission gear-wheels.
Being aware of the set rotation rate until which the revolutions of the electric motor decreases, the consumable electric current value I_3 can be calculated according to the formula (11):

$$I_3 = \frac{E - \frac{n_{SL}}{k_n}}{R_{BATT} + R_E + R_R + R_{COMP} + R_D} \cdot D. \tag{11}$$

In the formula (11), the value E should be taken with the set rotations, when the electric motor is not loaded.
The power P_3 can be determined according to the formula (12):

$$P_3 = I_3 \cdot (U_{BAT} - I_3 \cdot R_{BATT}) . \qquad (12)$$

In order to calculate the electric power consumption during the assembly period, it is necessary to know separate parts of the assembly period, the time, when building of the electric motor's rotations t_{iesk} takes place, the time t_{skr}, when the nut is screwed with the set initial rotations and the reaction period t_r.

The time period, when fastening t_{piev} of a nut takes place is not taken into account in calculations of the electric power consumption, since it is very short and has practically no effect on the result.

The electric power E for the assembly period can be calculated according to the formula (13).

$$E = P_1 \cdot t_{iesk} + P_2 \cdot t_{skr} + P_3 \cdot t_r . \qquad (13)$$

Despite the fact that simplified formulas (that are intended for electric motors with linear curves) were used for nutdriver's electric consumption calculations in which were not taken into account such electric motor's with magnetic excitation parameters as inductance of rotor coils L, the rotor coils resistance dependence on the temperature, the battery voltage and the electric power's dependence on its temperature, losses of electric power depending on frequency, they allow us to approximately determine the optimal operating mode for the nutdriver if taking into account electric power consumption, assembly time and necessary tightening moments for the different types of fixed threaded joints (metal, plastic, wood).

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