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IMPLEMENTATION OF THE MAXIMUM PERMISSIBLE OVERLOAD CAPACITY OF A DC MOTOR

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Abstract

DC motors, due to their wide applicability in various industrial sectors, necessitate precise control of their overload capacity to ensure safe and efficient operation. This study presents a comprehensive methodology for assessing the maximum permissible overload capacity of a DC motor. The core of this methodology lies in the derivation and application of the electromechanical characteristic equation of an electric drive with current cutoff. This equation serves as the foundation for constructing the electromechanical characteristics of the drive, providing a detailed representation of the motor's performance under varying operational conditions. A novel circuit is proposed, featuring an automatic adjustment mechanism for the cut-off current setting based on the speed of the electric drive. This adaptive circuit design ensures that the motor operates within its maximum permissible overload capacity, thereby optimizing performance and preventing potential damage due to excessive loads. By leveraging this advanced control methodology, the reliability and efficiency of DC motors in industrial applications can be significantly enhanced. This approach not only maximizes the motor's operational capabilities but also contributes to the overall safety and longevity of the electric drive systems.

Keywords: DC electric motor, drive, overload capacity, electromechanical characteristics, current cut-off, current limiting unit

I. Introduction

Direct current (DC) motors are widely used in various industrial and domestic applications due to their high reliability, ease of control and wide range of performance characteristics. An important aspect of the operation of electric motors is their overload capacity, that is, the ability to withstand a temporary increase in load torque beyond established limits without damage. Effective use of electric motors requires precise control and optimization of their overload capacity. This is especially important when operating under variable loads or in unpredictable environments. Failure to properly define overload limits can result in equipment damage, productivity and operational safety [1]. The purpose of the study is to improve the efficiency and reliability of electric motors by determining optimal overload values. The results obtained can be used in the design and operation of industrial equipment, as well as in the development of control and monitoring systems for the operation of electric motors.

If the operation of the mechanism is characterized by frequent starts and the speed of the drive is required, and its installed power is limited, then there is a need to fully use the maximum permissible overload capacity of the drive motor. Typically, such drives use DC motors. It is known that the permissible maximum torque and, therefore, the ultimate overload capacity of a DC motor varies depending on its speed. In short-term operating mode, the motor overload is limited mainly by the deterioration of the switching condition, leading to unacceptable sparking of the commutator-brush contacts of the machine.

The higher the rotation speed, the lower the armature current must be so that the switching conditions remain equally satisfactory [2, 5]. In reference materials, the value of the maximum permissible torque of DC motors is given for several speeds, usually for speeds $\omega \leq 0.2\omega_n$, $\omega=\omega_n$ and $\omega=2\omega_n$. So, for example, for a crane-metallurgical motor DP-82, 220V, PE=25% parallel excitation with a stabilizing winding, the curve for changing short-term permissible currents within the range of 0-$2\omega_n$ will have the form shown in Fig. 1 (broken line abc). Note that the diagram is constructed for the case where speed control up to $2\omega_n$ is carried out by changing the voltage applied to the motor armature and that the change in the permissible current between given points ab and c is taken along a straight line. Let's consider the possibilities of ensuring that existing circuits of automated electric drives make full use of the maximum overload capacity of the electric motor, that is, automatically limiting the drive load current along the line of permissible overloads indicated in Fig. 1.

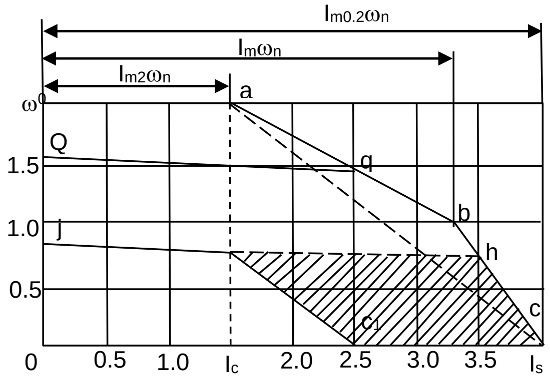

Figure 1: *Scheme for automatically limiting the drive load current along the permissible overload line*

II. Methods

Typically, in automation circuits, in order to limit motor overload, a current cut-off unit is used (Fig. 2.). The independent excitation electric motor receives power from a controlled energy converter containing a control signal adder with windings CW1 and CW2. The circuit of the current cut-off unit includes a shunt with resistance rs, connected to the motor armature circuit, a source of reference (reference) voltage RV, winding CW2 and diode D.

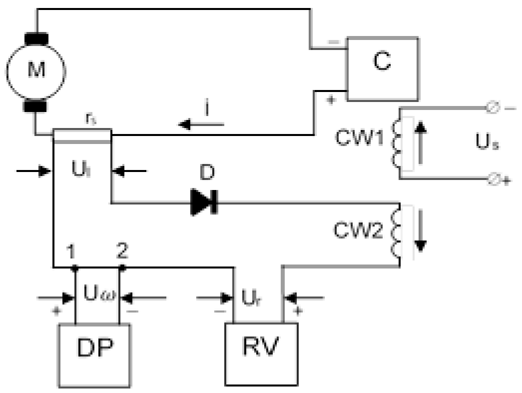

Figure 2: *Automation circuit for limiting motor overload using a current cut-off unit*

The equation for the electromechanical characteristics of an electric drive with current cut-off can be presented in the following form:

$$\omega = \frac{k_g(U_\Sigma)}{k\phi} \cdot U_s - \frac{r_c + r_m}{k\phi} \cdot I - \frac{k_c(U_\Sigma) \cdot r_s}{k\phi} \cdot (I - I_c) \cdot l(\Delta I) \qquad (1)$$

Where $k_g(U_\Sigma)$ and r_c are the gain of the total input voltage and the output resistance of the converter, respectively; I and r_m are the current and resistance of the motor armature circuit, respectively; U_s – setting voltage; I_c – cut-off current, I_c=const; U_r – reference voltage; k – electromagnetic constant; ϕ – motor excitation flux ϕ=const.

When deriving formula (1), it was accepted that: a) $l(\Delta I)$ is a unit function equal to 0 or +1, respectively, for armature currents lower and higher cutoff currents; b) control windings CW1 and CW2 of the signal adder are identical [3]. The electromechanical characteristics of the drive, constructed according to equation (1) when speed is controlled by armature voltage, for various values of U_s are shown in Fig. 3, a. When $I \le I_c$, no current flows through winding CW2 and the electric drive operates in the operating range of the characteristic. When $I > I_c$, current begins to flow through winding CW2, U_Σ decreases and the motor torque is limited.

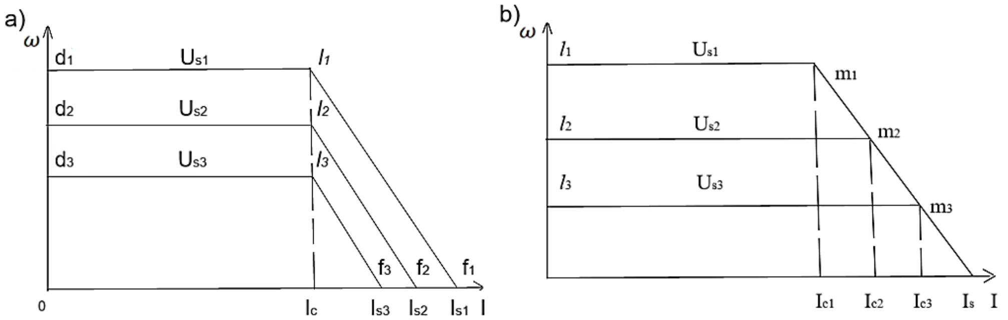

Figure 3: *The electromechanical characteristics of the drive, constructed according to equation (1) when speed is controlled by armature voltage, for various values of* U_s

Let us assume that for this electric drive, by selecting the parameters of the current cut-off unit, the coincidence of section e_1f_1 of the electromechanical characteristic curve at U_{s1} (Fig. 3, a) with section bc of the curve of permissible maximum currents (Fig. 1) is achieved. In this case, using a conventional current cut-off unit, it is possible to automatically limit the armature current along the line of permissible motor currents if the value of the setting signal corresponds to the value of U_{s1}. At lower values of the setting signal, the armature current limitation will pass through lines e_2f_2 or e_3f_3 depending on the value of the setting signal U_{s2} or U_{s3}, i.e. in this case, the armature current will be limited at currents less than permissible values [7-9]. Consequently, when using a conventional current cut-off unit, with driving signals less than the nominal value (if U_{s1} is taken as the nominal value of the driving signal), full use of the permissible overload capacity of the electric motor is not ensured. The underutilization of the maximum overload capacity becomes even greater if the electric drive provides for regulation of the motor rotation speed above the rated speed. In this case, the diagram of the maximum permissible currents for a given motor will have two limitation sections (ab and bc, Fig. 1) with two different slopes of each of them. Since the electromechanical characteristic of an electric drive using a conventional current cut-off unit has only one current limiting section, this unit would have to be adjusted along the dotted line ac (Fig. 1) to the cut-off current $I_c = I_{m2\omega n}$ and to the stopping current $I_s = I_{m0.2\omega n}$. In this case, at all values of the setting signal, there will be an underutilization of overload torques.

The degree of underutilization of the maximum overload capacity of the engine for various values of the master signal can be conditionally estimated by a coefficient equal to the ratio of the areas limited by the coordinate axes (I and ω) and the corresponding mechanical characteristics.

So, for example, for electric motors that allow speed control up to 2ω_n:

$$k_1 = \frac{s_{oc_1 a_1 i}}{s_{ochj}} \text{ for } \omega_s = 0.8 \cdot \omega_n$$

Based on the calculated values of k_1 for DP-82 engines, the graph shown in Fig. 4 was constructed. As can be seen from the k_1 curve, the underutilization of the maximum overload capacity of the motor at reference speeds below 0.6ω_n reaches more than 50%. From the above, we can conclude that adjustable DC electric drives with existing current limiting units do not ensure full use of the maximum overload capacity of the motor [11-13]. In this regard, a new current cut-off circuit is proposed for adjustable DC electric drives, which makes it possible to fully realize the maximum overload capacity of the electric motor over the entire speed control range (at all values of the set signal).

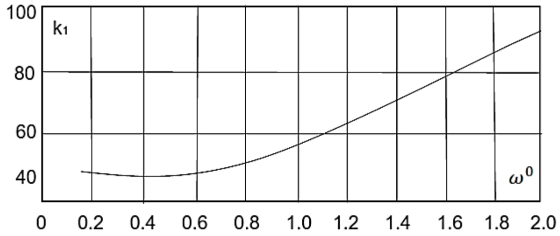

Figure 4: *Graph based on calculated values of k1*

The main reason for the shortcomings of the existing current cut-off unit is the independence of the cut-off current value from the setting signal Us. Indeed, at the beginning of the cutoff circuit, the voltage drop across the shunt U_1 is equalized with the reference voltage and the cutoff current:

$$I_c = \frac{U_r}{r_s} = const$$

It follows that the overload limiting unit in the new circuit must be designed in such a way that the comparison voltage does not remain a constant value, but changes as a function of the change in the maximum permissible armature current from the motor speed. For this purpose, an additional signal from the speed sensor SS is added to the circuit of the existing video current cutoff (Fig. 2, the U_ω signal is introduced into section 1-2). The speed sensor signal U_ω, subtracted from the reference voltage, forms a comparison voltage (U_a), the value of which, being a function of speed, increases as the engine speed decreases. Due to this, the cut-off current becomes a function of the motor speed. In this case, at the moment the cutoff begins, there is a voltage balance:

$$U_I = U_a = U_r - U_\omega = I_c r_s$$

Where does the cutoff current come from:

$$I_c = \frac{U_r - U_\omega}{r_s} = \frac{U_r}{r_s} - \frac{k_\omega}{r_s} \cdot \omega$$

While $U_I \le U_a = U_r - U_\omega$, the engine operates in the working section of the speed characteristic. When $U_1 > U_a$, current begins to flow through the control winding CW2, as a result of which the motor torque is limited. Moreover, as the set speed decreases, the cutoff current increases to the permissible overload for a given motor speed. This can be seen from Fig. 3b, which shows graphs of the electromechanical characteristics of the drive, constructed according to the equation:

$$\omega = \frac{k_c(U_\Sigma) \cdot U_s - (r_c + r_m) \cdot I - k_c(U_\Sigma) \cdot (I r_s - U_r l(\Delta I)}{k\phi + k_c(U_\Sigma) k_\omega l(\Delta I)} \tag{2}$$

The expression for the stopping current can be obtained from equation (2) by substituting the values of ω=0 and I=I_s. In this case we get:

$$I_s = (U_r + U_s) \cdot \alpha \tag{3}$$

Where:

$$\alpha = \frac{k_c(U_\Sigma)}{r_c + r_m + k_c(U_\Sigma) r_s} \approx const$$

As can be seen from (3), in the proposed current cut-off circuit, the value of the stopping current varies slightly depending on the value of the setting signal; the stopping current decreases as the driving signal decreases. To reduce the influence of this dependence, the ratio U_{smax}/U_r should be taken to be small. To fully utilize the maximum permissible overload capacity of the electric motor when regulating the speed down from the nominal value of the parameters U_r, k_ω, r_s should be selected in such a way that the steeply falling part of the electromechanical characteristics (line m_1n, Fig. 3, b) coincides with the line of the maximum permissible motor currents (bc, Fig. 1). Then, regardless of the reference speed, the overload current limitation will always be along the line of the maximum permissible motor currents and, therefore, the use of the maximum overload capacity for all speeds will be complete [15]. As mentioned above, for an electric drive that requires speed control up to 2ω_n, the current limiting curve should have the shape of a broken line abc (Fig. 1). In this case, to change the slope of the current limiting curve, you can use a relay with a high return coefficient connected to the signal voltage of the speed sensor SS. By triggering this relay, upon reaching the rated rotation speed, the parameters of the current cut-off circuit (U_r, k_ω, r_s) are changed and the required change in the slope of the current-limiting section of the electromechanical characteristic is ensured. In this case, the electromechanical characteristics of the drive for set speeds, for example, 0.8ω_n and 1.5ω_n, will be obtained in the form of broken lines, jhc and pqbc, respectively (Fig. 1). Consequently, the maximum overload capacity of the drive motor will also be fully realized for any value of the reference rotation speed.

III. Results

1. The existing current limiting unit does not ensure full use of the maximum overload capacity of a DC motor, especially for master signals less than the nominal one. At reference speeds below 0.6ω_n, the underutilization of the maximum overload capacity of the motor reaches more than 50%.
2. In order to automatically limit overload along the line of permissible values of motor currents, you can use the proposed current cut-off unit.

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