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Calculation of Starting and Breaking Times of Induction Motor Electric Drives, for Different Mechanical Loads

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Abstract – **In this paper one simple method, based on Kloss equation, for starting and breaking times calculation of induction motor electric drive, using MATLAB simulation program is presented. Several typical torque-speed characteristics of the mechanical loads are given, for which the specified times are calculated. The MATLAB program is used to perform the torque – speed characteristics of the motor and the load, as well as the speed characteristics in function of time. The accurate calculation of acceleration and deceleration time and selecting an adequate profile, is one of the most important task for designing the electro-mechanical equipment for a high efficient electric drive system in industry application.**

Keywords – **Induction motor, electric drive, mechanical characteristic, MATLAB, starting and breaking times.**

I. INTRODUCTION

Determination of the acceleration and deceleration times of the electric drive is of great practical importance, especially in the case of load mechanisms with frequent starts and stops. In such cases, the operating time of the mechanism in a non-stationary regime can substantially exceed the time with stationary speed and may have a crucial impact on the working machine productivity.

Some algorithms attempt to utilize the advantages of both regenerative braking and hand plug breaking simultaneously and shows that: regenerative breaking is efficient in the context of energy regeneration but it has poor braking time performance; while plug braking is faster without any regeneration of kinetic energy [1]. From an electrical point of view, one of the important factors is that during the acceleration or/and deceleration periods in motion control, the drive motor most often demands an increased current from the power grid. For the purpose of the electrical equipment optimal design, it is necessary to know the duration of these transient regimes [2].

Determining the duration of mechanical transient regimes is based on the integration of the motion equation, through which the dynamic torque of the system is expressed, as the basic factor for the acceleration, i.e. the deceleration:

$$M_m = M_s + M_d = M_s + J\frac{d\omega}{dt} \tag{1}$$

$$M_d = J\frac{d\omega}{dt} = \frac{mD^2}{38{,}2}\cdot\frac{dn}{dt} \tag{2}$$

$$dt = \frac{J}{M_m - M_s}d\omega = \frac{mD^2}{38{,}2(M_m - M_s)}dn \tag{3}$$

$$t_p = \int_0^n \frac{mD^2}{38{,}2(M_m - M_s)}dn \tag{4}$$

The general conclusion can be drawn that the starting time t_p in equation (4) is proportional to the moment of inertia of the electric drive, and inversely proportional to the dynamic torque. For braking regime, the motor electromagnetic torque receives the reverse sign, so the dynamic moment, as shown in equation (5), changes. In this case the breaking time t_s can be calculate as:

$$t_s = \int_0^n \frac{mD^2}{38{,}2(M_m + M_s)}dn \tag{5}$$

II. TORQUE-SPEED CHARACTERISTICS OF INDUCTION MOTOR AND LOADS

To determine the time integral of the equations (4) and (5), it is necessary to know the dependencies: $M_m=f(n)$ – motor torque-speed characteristic and $M_s=f(n)$ – load characteristic. In standard squirrel cage induction motors with low conductive bars that have no significant effect of current suppression, as well as in wound rotor induction motors, transient regimes can be analysed with the simplified form of the Kloss equation [3]. The torque-speed characteristics of the load mechanisms can be very complex functions that depend of multiple variables. In practice, the most common forms of the load torque characteristics are:

$M_s = 0$ - no-load regime;

$M_s = M_n = const;$

$M_s = kn$ - crane or generator type load (torque proportional to speed);

$M_s = kn^2$ - fan (centrifugal) type load (torque proportional to square of the speed);

$M_s = \frac{k}{n+c}.$ - constant power type load (torque inversely proportional to speed)

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III. MATLAB PROGRAM

For different type of loads, integral function in equations (4) and (5) can be very complex for calculation and therefore is used some techniques for numerical integration. The user-oriented program for time calculation is prepared in MATLAB [4]. This program is aimed for standard type of squirrel cage induction motor and for different type of loads.

The necessary data for calculation is motor catalogue values: rated power, rated speed, synchronous speed, rated current, energy efficiency, power factor, I_p/I_n, M_p/M_n, M_k/M_n, rated voltage and moment of inertia.

Calculation of motor torque-speed characteristic is made with simplified Kloss equation. Starting and breaking times is determined with square (parabolic) interpolation for uniform distribution of the selected points for speed. Additionally program is drawing the time dependence of drive speed vs. starting and breaking time in per units system.

IV. MOTOR PARAMETERS

The examined electric motor is squirrel cage motor with these parameters:

U_n=380 V; P_n=2,2 kW; n_n=1400 min^{-1}; n_0=1500 min^{-1}; η=81 %; cosφ=0,83; I_n=5 A; I_p/I_n=6,3; M_p/M_n=1,7; M_k/M_n=2,7; J=0,00818 kgm^2.

V. RESULTS

Following, the results of all five torque-speed characteristics for different mechanical loads are present and discussed. For the purpose of result assessment and comparing, all electric drive acceleration processes are simulated up to the same steady operating point, defined with the rated speed and torque. For each mechanical load characteristic three appropriate MATLAB generated graphs are discussed:

a) torque speed characteristics of the induction motor and of the mechanical load are expressed in per unit system and in percent; the rotor speed in terms of synchronous speed and the developed electromagnetic torque in terms of maximum torque.

b) Rotor speed transient characteristic depending on starting time t_p is expressed in per unit system. Mechanical rotational speed is expressed in terms of rated speed, while the starting time t_p is expressed in percentage from the total acceleration time performing via MATLAB calculation.

c) Rotor speed transient depending on breaking time t_k is expressed in per unit system. Mechanical rotational speed is expressed in terms of rated speed, while the breaking time t_k is expressed in percentage from the total deceleration time performing via MATLAB calculation.

As a good approximation, the total motor axis moment of inertia J_{vk} is considered to have a value of $2 \cdot J_{mot}$, meaning that mechanical load has the same inertia moment as the induction motor

The reverse current braking (plugging) of the induction motor is realized by utilizing the reverse polarity.

All steady state mechanical loads are assumed to be reactive e.g. opposite of electric drive rotation.

***No-load regime (M_s=0)**

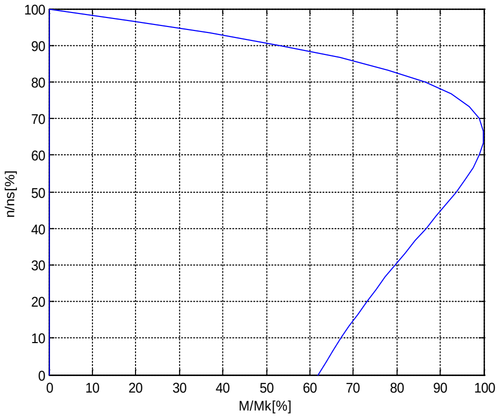

Fig. 1.Torque-speed characteristic (M_s=0)

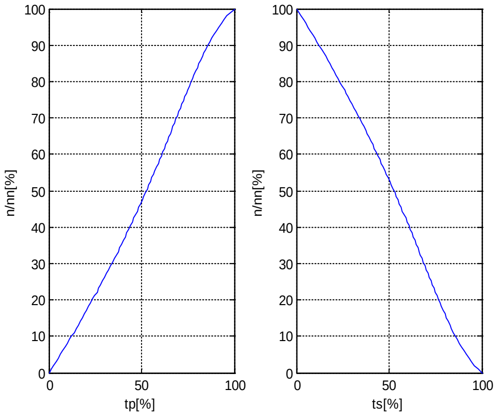

Fig. 2. Starting t_p and breaking t_s time in per units

t_p=0,0753 (s) and t_s=0,0753(s)

***Constant torque (M_s=M_n=const)**

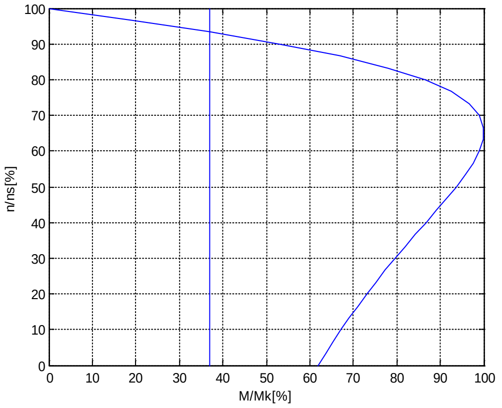

Fig. 3. Torque-speed characteristics (M_s=M_n=const)

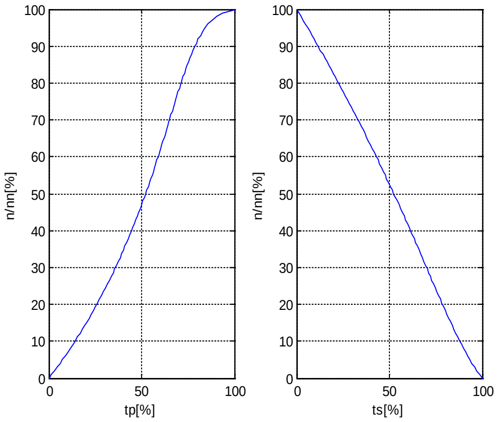

Fig. 4. Starting t_p and breaking t_s time in per units
t_p=0,1525 (s) and t_s=0,0499(s)

*Torque proportional to speed (M_s=k·n, where k=M_n/n_n)

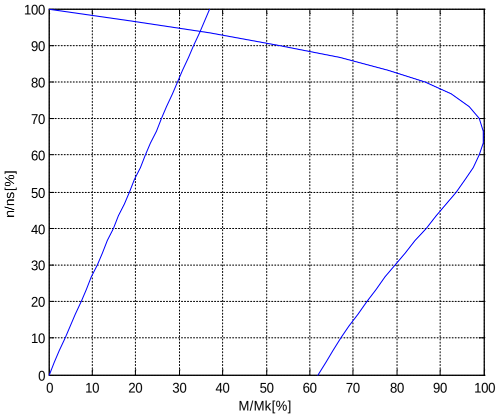

Fig. 5. Torque-speed characteristics (M_s=k·n, where k=M_n/n_n)

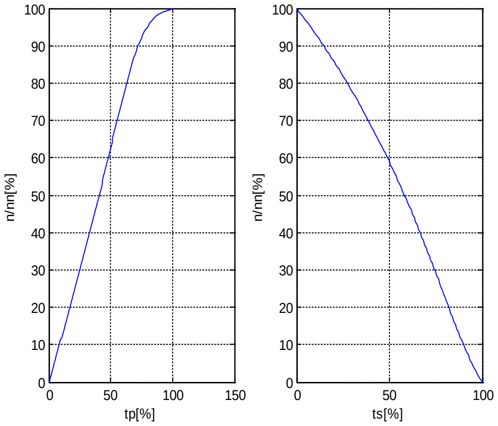

Fig. 6. Starting t_p and breaking t_s time in per units
t_p=0,1079 (s) and t_s=0,0611(s)

*Torque proportional to square of the speed (M_s=k·n^2, where k=M_n/n_n^2)

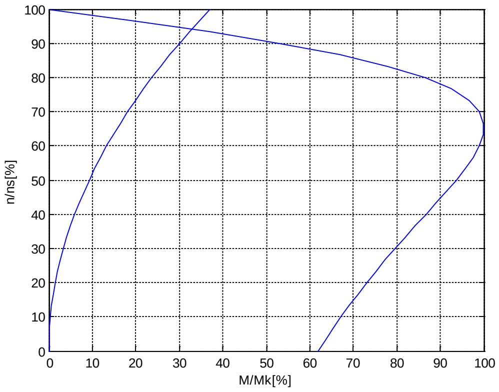

Fig. 7. Torque-speed characteristics (M_s=k·n^2, where k=M_n/n_n^2)

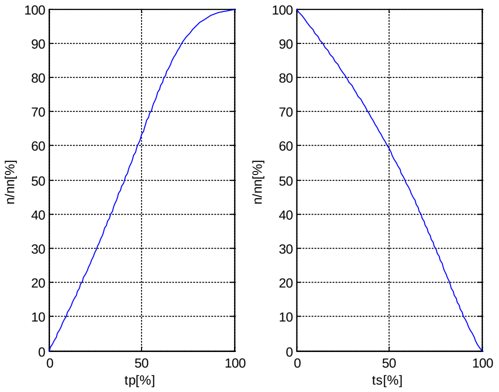

Fig. 8. Starting t_p and breaking t_s time in per units

t_p=0,0991 (s) and t_s=0,0650(s)

*Torque inversely proportional to speed (M_s=k/(n+c), where k=2,67·n_n·M_n and c=n_n/0,6)

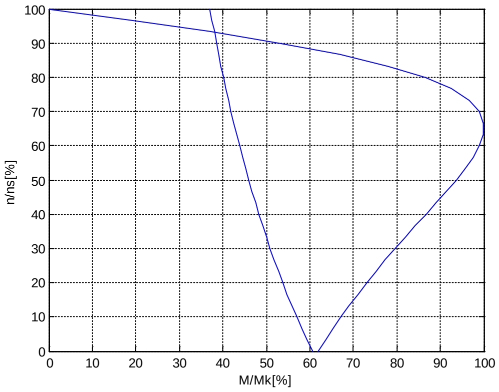

Fig. 9. Torque-speed characteristics (M_s=k/(n+c), where
k=2,67·n_n·M_n and c=n_n/0,6)

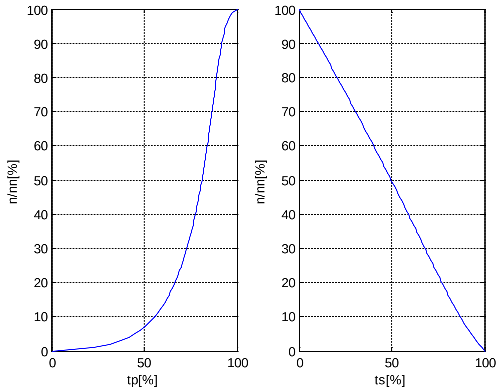

Fig. 10. Starting t_p and breaking t_s time in per units t_p=0,4009 (s) and t_s=0,0458(s)

VI. CONCLUSION

From the obtained results and diagrams is it shown that the most difficult start of the electric drive occurs at constant power type mechanical load, where the mechanical torque is inversely proportional to the speed. The next heavy mechanical load is with constant mechanical torque. As a most convenient light drive (except no-load starting) is considered the fan or centrifugal type load where the mechanical torque is proportional to square of the speed.

This is expected outcome, because the acceleration time is inversely proportional to the dynamic torque. In this case dynamic torque is represented as a difference between motor torque and load torque.

From the torque speed diagrams follows the bigger the area limited by the motor- and by the load- torque-speed characteristic, the shorter is the drive starting time.

On the other side as already mentioned, all mechanical loads are treated as reactive, and as a result that during the breaking regime of operation the electromagnetic torque and load torque are in the same direction, the load with the most difficult start, will have the shortest breaking time.

The equation of the starting- and breaking time is a fundamental integral and can be easily solved for the case of dynamic torque-speed linearity function. But in case of complicated mechanisms, with high order function of the torque-speed characteristic, integral equation becomes more complicated and only iterative based method solution is possible. For this purpose, we design a MATLAB based program solution, with no function restriction to the sub integral part of the starting or breaking time equation.

The developed program gives fast and accurate starting and breaking time calculation for the drive system with the standard squirrel cage induction motor and freely chosen mechanical load.

Furthermore, this approach considerably improves the drive protection possibilities, can enhanced the drive efficiency and improve dynamic and thermal properties of the induction motor.

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