Mechatronics 000 (2016) 1–10

Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

An almost comprehensive approach for the choice of motor and transmission in mechatronics applications: Motor thermal problem

Giancarlo Cusimano*, Federico Casolo*

Dipartimento di Meccanica, Politecnico di Milano, Via Giuseppe La Masa 1, 20156 Milan, Italy

ARTICLE INFO

Article history:
Received 16 February 2016
Revised 10 June 2016
Accepted 23 September 2016
Available online xxx

Keywords:
Motor-transmission coupling
Servo-motor
Transmission
Transmission efficiency
Transmission inertia

ABSTRACT

This paper deals with the choice of motor and transmission in mechatronic applications by means of an approach in which all the following aspects related to the transmission are taken into account from the outset: the limits of speed and torque of the transmission; the alternation in the reference task of direct and inverse efficiency of the transmission, which can also be functions of the motor speed; the transmission inertia. In this paper only the continuous duty operating range of the drive system is considered. The method is based on the determination of the motors that can be coupled with a given transmission and is explained by means of resolving diagrams. The guidelines of an automatized procedure for the determination of the admissible drive system-transmission couples are traced and a case study is presented.

1. Introduction

The simultaneous choice of drive system and transmission in mechatronic applications, which present high dynamic loads, must take into account the characteristic parameters and limitations presented by both the components. For the drive system the parameter is the motor inertia and the limitations are the continuous duty and the dynamic operating range. For the transmission the parameters are the transmission ratio, the direct and inverse efficiency, which can be also variable with the speed, the moment of inertia on motor-side and load-side, while the limitations regard its maximum torque and speed.

Many authors developed methods for the simultaneous choice of motor and transmission. Normally, the motor is considered with the 'complete' set of its characteristics that is interesting to emphasize, whereas only the reducer transmission ratio is taken into account [1–9]: therefore this is only a preliminary choice that must be followed by a further verification, in which, taking into account all the transmission characteristics, the designer can establish if the drive system-transmission couple is actually admissible. In short, some characteristics of the transmission are initially neglected and are taken into account at a second stage. The proposed methods, except for [5], in general regard either the continuous duty or the dynamic operating range of the drive system, even though both must be taken into account in order to couple drive system and transmission.

The direct reducer efficiency η_d and the inverse η_i are taken into account from the outset in the following papers.

In [10,11] Giberti et al. extend the method presented in [5] by taking into account the transmission efficiency with reference to the continuous duty operating range. Furthermore, during the reference task, the mechanical power through the transmission has only one direction, either direct or inverse.

In [12] Cusimano deals with the selection of the motor-transmission couple with reference to the torque peak of the motor by taking into account the transmission efficiencies. The paper considers the general case, in which, during the reference task, the power direction through the transmission changes alternately.

In [13] Roos et al., after a feasibility analysis, introduce different optimization criteria in order to choose the best motor-transmission pair. Only the direct transmission efficiency is taken into account.

In [14] Cusimano explains the issues arising in the case of a non-rectangular dynamic range of the drive system and how the design method presented in [5,7] can be modified, taking into account the transmission efficiencies.

In all these papers the transmission efficiencies do not change with speed.

The present paper introduces the most general case, in which, during the reference task, there is alternation between direct and inverse power direction through the transmission. This is a very common case in mechatronic applications where the inertial forces play an important role. This distinction can change the design results. As will be seen in Section 6.3.2., to neglect the alternation of the power flow through the transmission can imply:

* Corresponding authors. Fax: +39223998492.
E-mail addresses: giancarlo.cusimano@polimi.it (G. Cusimano), federico.casolo@polimi.it (F. Casolo).

http://dx.doi.org/10.1016/j.mechatronics.2016.09.004

- The exclusion of a motor that on the contrary is admissible.
- The reduction of the set of reducers that can be coupled with an admissible motor.

These observations show that if the designer desires to decrease the rated torque of the motor, to take into account the alternation between direct and inverse efficiency can help him to find an admissible and satisfactory motor-transmission couple.

Furthermore this paper introduces the case in which the transmission efficiencies are not constant, but depend on the motor speed, as in the harmonic drives.

This paper adopts an approach in which from the outset all the characteristics of the transmission are taken into account in an almost comprehensive and systematic way, while also all the parameters and limitations of the drive system are simultaneously considered. As regards the drive system, this paper only considers its continuous duty operating range, whereas, for the sake of shortness, its dynamic operating range will be taken into account in a next paper.

A first step is devoted to establish if the transmission is admissible, i.e. if independently of the motor its limitations make it able to drive the load. Then, for each admissible candidate transmission it is possible to determine all the candidate motors that can be coupled with it in order to perform the reference task.

The procedure is derived by distinguishing two complementary load torques, functions of time, related to the direct and inverse efficiency conditions, respectively.

For the proposed approach new and simple resolving diagrams are used. The paper also indicates the guidelines of an automatized procedure for the determination of the admissible drive system-transmission couples.

In particular, in this paper Section 2 describes the quantities characterizing drive system and transmission. Section 3 indicates the specifications regarding the load and explains the constraint inequalities regarding both motor and transmission. Section 4 states the motion equations of the system. Section 5 reports a method to take into account efficiencies and moments of inertia of the transmission. Section 6 takes a given transmission into account, excludes it if this does not meet the corresponding constraint inequalities, otherwise proposes diagrams which permit the designer to identify the motors that can be coupled with the given transmission in order to perform the reference task. Section 7 indicates the guidelines of an automatized procedure for the determination of the admissible drive system-transmission couples. Section 8 discusses a case study. Finally, Section 9 presents the conclusions.

2. Drive system characterization and task specifications

The model of the machine, shown in Fig. 1, consists of three serial elements: motor, transmission and load. The load torque M_L exerted on the joint takes into account both inertial and resistant contributions.

This paper considers an electrical motor, whose variable torque and speed are indicated by M_m and ω_m, respectively. Its unknown moment of inertia is J_M. It is assumed that the motor operating ranges are symmetrical on the four quadrants.

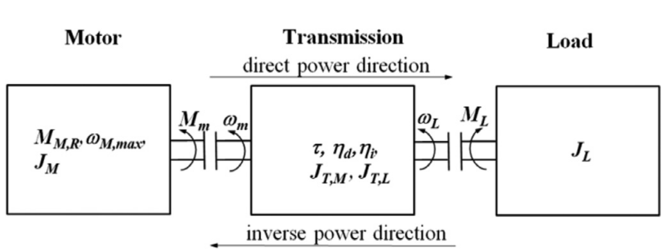

Fig. 1. Model of the machine.

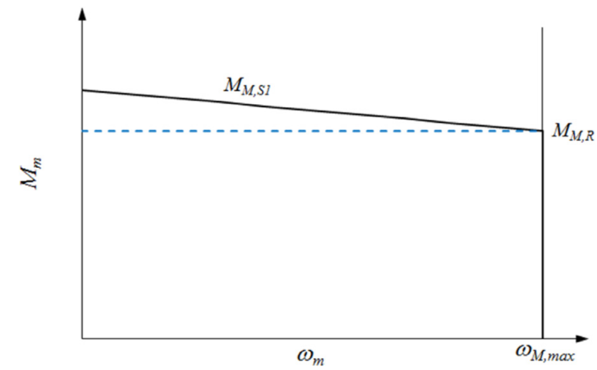

Fig. 2. Continuous duty operating range of the drive system and its schematization.

The continuous duty operating range on the first quadrant is shown in Fig. 2. It is limited by the maximum angular speed $\omega_{M,\max}$ achievable by the motor and a torque $M_{M,S1}$, which slowly decreases with the motor speed ω_m (Fig. 2). $M_{M,S1}$ is due to the maximum temperature that the motor can withstand. In the following, a simplified continuous duty range of the brushless motor is taken into consideration, with a constant torque equal to the rated torque $M_{M,R}$, as shown in Fig. 2.

In mechatronic applications, the reference task is periodic and the rms motor torque must not be higher than $M_{M,R}$: this guarantees that the motor does not burn during its periodic working (motor thermal problem).

The dynamic operating range of the drive system is not considered in this paper and will be taken into account in a next work.

Between motor and load, the reducer has a transmission ratio τ, which is the ratio between load speed ω_L and motor speed ω_m and, for the sake of simplicity, is considered positive. The direct transmission efficiency is η_d, the inverse one is η_i. The moment of inertia of the shaft connected to the motor is $J_{T,M}$ and that of the shaft connected to the load is $J_{T,L}$. It is clear that the transmission can also be linear, with the suitable dimensional changes following for the involved quantities.

A transmission is also characterized by many other parameters related to the limits of speed and torque of this component. For the sake of simplicity, in this paper only two parameters are considered: the maximum admissible speed $\omega_{T,M,\max}$ on motor-side and the maximum admissible torque $M_{T,L,\max}$ on load-side. However, the method presented in this paper can be suitably extended to the case of more numerous and complex parameters.

3. Specifications and constraint inequalities

In a periodic reference task whose period is T the rms value of the motor torque is equal to

$$M_{m,rms} = \sqrt{\frac{1}{T}\int_0^T M_m^2(t)dt} \tag{1}$$

The maximum absolute value of the motor speed is equal to

$$\omega_{m,max} = \max_t [|\omega_m(t)|] \tag{2}$$

The two constraint inequalities that a drive system must satisfy are [5,6]:

$$\begin{cases} M_{m,rms} \le M_{M,R} \\ \omega_{m,max} \le \omega_{M,max} \end{cases} \tag{3}$$

Please cite this article as: G. Cusimano, F. Casolo, An almost comprehensive approach for the choice of motor and transmission in mechatronics applications: Motor thermal problem, Mechatronics (2016), http://dx.doi.org/10.1016/j.mechatronics.2016.09.004