ELECTRIC DRIVES

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Electric Drives

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Preface

The present book is meant for undergraduate and postgraduate students in electrical, electrical & electronics, power electronics and automation courses of all engineering colleges (B.E./B.Tech./M.E./M.Tech./Ph.D.). It presents a unique self-study material on electrical drives, solid-state drives, industrial drives and power semiconductor drives. Solved and unsolved problems, multiple-choice questions of different patterns have been given to the students for practice. Chapter 1 describes the general introduction about drives. Chapter 2 gives information related to components, applications and factors affecting the selection of electrical drives. The remaining chapters provide all the required information about the electrical drives. A large number of solved and unsolved problems with answers make this book suitable for undergraduate and postgraduate courses in electrical drives. Practising engineers and those appearing for engineering services/ GATE examinations IES/IAS will also find this book useful.

Suggestions for further improvement of the book will be appreciated.

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Rakesh Singh Lodhi

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1 Introduction

1.1 INTRODUCTION

Automation control, motion control, and machine automation systems are used to improve manufacturing performance and flexibility. Engineering assistance with machine safety, energy efficiency, and motion control by braking system automation concepts, global application expertise, and support, reduce energy consumption. Improved workers' safety makes more effective use of new, integrated approaches to complex challenges of engineering. A production machine requires high precision movement, or just simple positioning. Integrated motor-drive technology implements this architecture, distributing functions such as motion control, safety and predictive maintenance to individual drives.

Nowadays modern controllers such as proportion controller, Norma L-2 controller deliver many more tasks and carry them out with great precision to incorporate both power electronic devices, microprocessors and microcontrollers. For many years, the motor controller was a box which provided the motor speed control and enabled the motor to adapt to variations in the load.

The tasks for modern control are:

- to control the transients and dynamics of the electrical or mechanical machine and apply its response to loads;
- to provide electronic commutation;
- to enable self-starting of the motor;
- to protect the motor and the controller from damage;
- to match the power from an available source to suit the requirements of the motor (voltage, frequency, number of phases); and
- to provide pure DC or AC power free from harmonics or interference so that it can be an integral part of a generator control system. Power conditioning could also be provided by a separate free standing module operating on any power source.

1.2 DRIVES

Motion control is required in a large number of industrial and domestic applications such as transportation systems, rolling mills, textile mills, machine tools, fans, motor pumps, robots, washing machines, etc. Systems employed for rotation control or speed control are called ***drives***, and may employ any of the prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors, hydraulic turbines and electric motors, for supplying mechanical energy or electrical energy for motion control.

Definition: *The systems that are employed for motion control are called* ***drives.***

1.3 CLASSIFICATION OF DRIVES

1.3.1 Based on the Mode of Operation

(1) Continuous duty drives: The motor works at a constant load for enough time to reach temperature equilibrium.
(2) Short time duty drives: The motor works at a constant load, but not long enough to reach temperature equilibrium. The rest periods are long enough for the motor to reach ambient temperature.
(3) Intermittent duty drives: Sequential, identical run and rest cycles with a constant load. Temperature equilibrium is never reached. Starting current has little effect on temperature rise.

1.3.2 Based on Means of Control

(1) Manual control drives: The drives with manual control can be either simple as a room fan or complicated as a push button starter.
(2) Semi-automatic control drives: Drives consisting of a manual device for giving a command and automatic device in response to a command.
(3) Automatic control drives: These drives have a control gear, without the manual device, are known as automatic control drives.

1.3.3 Based on Number of Machines

Individual electric drive: In this drive, each individual machine is driven by a separate motor. This motor also imparts motion to various parts of the machine.

- **Group drive:** This drive consists of a single motor, which drives one or more line shafts supported on bearings. The line shaft may be fitted with either pulleys and belts or gears, by means of which a group of machines or mechanisms may be operated. It is also sometimes called shaft drive.

- **Multi-motor electric drive:** In this drive, each operation of the mechanism is taken care of by a separate motor drive. In this drive system, there are several drives, each of which serves to actuate one of the working parts of the drive mechanisms.

1.3.4 Classification Based on Dynamics and Transients

(1) Independent transient period
(2) Dependent transient period

1.3.5 Classification Based on Methods of Speed Control

(1) Reversible and non-reversible independent constant speed.
(2) Reversible and non-reversible step speed control.
(3) Variable position control.
(4) Reversible and non-reversible smooth speed control.

1.4 ADJUSTABLE SPEED DRIVE (ASD) OR VARIABLE SPEED DRIVE (VSD)

It describes the equipment that is used to control the speed of machines. Many industrial processes such as assembly lines operate at different speeds for different products. Where process conditions demand adjustment of flow from a motor pump or fan, varying the speed of the drive may save energy compared with other techniques for flow control.

An adjustable speed drive is defined as the speed that may be selected from several different pre-set ranges. If the speed output can be changed without steps over a range, the drive is known as variable-speed drive.

1.4.1 Benefits of ASD

1. Smooth operation
2. Acceleration control
3. Different operating speeds
4. Compensate for changing process variables
5. Allow slow operation for setup purposes
6. Adjust the rate of production
7. Allow accurate positioning
8. Control torque or tension

1.5 FACTORS AFFECTING SELECTION OF DRIVES

(i) Steady-state operation needed: Behaviour of speed torque curve, speed regulation, speed range, efficiency, duty cycle, quadrant of operation, speed fluctuation, ratings.

(ii) Requirements of transient operation: Acceleration and deceleration, the performance of starting, motoring, breaking and reversing.

(iii) Source needed: Type of source, and its capacity, voltage magnitude, voltage fluctuations, power factor, harmonics and its effect on loads, ability to accept regenerated power.

(iv) Capital and running cost, maintenance needs, life

(v) Space and weight restriction

(vi) Reliability

1.6 CHOICE OF DRIVES

(i) Space requirement

(ii) For operation and maintenance, skilled personnel are needed

(iii) Obtainability of spare parts

(iv) Noise and other ecological considerations

(v) Consistency of drive like frequency of breakdown, up and down times

(vi) Operating cost, maintenance cost, etc.

(vii) Overall initial investment required

(viii) Load requirements, i.e., steady-state torque speed, characteristics of load, variable speed range required, duty cycle, whether the reversible process is required, a rating of the drive, etc.

(ix) Starting and braking requirements. The time required for accelerating to full speed, the time required for braking, the time required for reversal of the direction of rotation, etc.

1.7 APPLICATIONS OF DRIVES

There are many applications of drives. The selected ones are:

(1) Complicated metal cutting machine tools
(2) Paper making industry or paper mills
(3) Rolling machines or rolling mills
(4) Belt drives in mechanical systems
(5) Chain drives in mechanical systems
(6) Electrical motor drives in electrical systems
(7) Power electronics equipment in electrical systems
(8) Cement kilns or cement mills
(9) Aerospace actuators
(10) Automotive applications or automation system
(11) Robotic actuators
(12) Flexible manufacturing systems

1.8 LOAD EQUALIZATION

In the method of load equalization intentionally the motor inertia is increased by adding a flywheel on the motor shaft if the motor is not to be reversed. For effectiveness of the flywheel, the motor should have a prominent drooping characteristic so that on load there is a considerable speed drop.

In applications such as an electric hammer, pressing job, steel rolling mills, etc., load fluctuates widely within short intervals of time. In such drives, to meet the required load

Here
Tl is load torque;
Tlh is torque when current is maximum at th time; and
tl is time when current will be minimum.

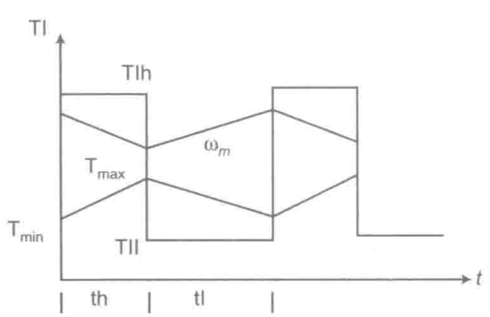

Fig. 1.1 Torque-time curve for load equalization.

the motor rating has to be high, or the motor would draw the pulse current from the supply. Such pulse current from the supply gives voltage fluctuations which affect the other load connected to it and affects the stability of the source. The above problem can be met by using a flywheel connected to the motor shaft for non-reversible drives. This is called load equalization. The moment of inertia and the mechanical time constant can be found out from the load equalization problem.

When an electric motor rotates, it is usually connected to a load which has a rotational or translational motion. The speed of the motor may be different from that of the load. To analyze the relation between the drives and loads, the concept of dynamics of electrical drives is introduced.

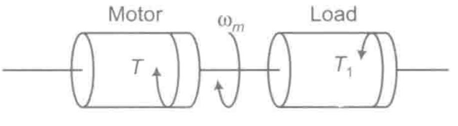

Fig. 1.2 Rotational system.

Motor load system

where

J = Polar moment of inertia of motor load

ω_m = Instantaneous angular velocity

T = Instantaneous value of developed motor torque

T_1 = Instantaneous value of load torque referred to motor shaft

Now, from the fundamental torque equation

$$T - T_1 = \frac{d}{dt}(J\omega_m) = J\frac{d\omega_m}{dt} + \omega_m \frac{dJ}{dt}$$

For drives with constant inertia

$$\frac{dJ}{dt} = 0$$

Therefore, $T = T_1 + J\,\dfrac{d\omega_m}{dt}$

So, the above equation states that the motor torque is balanced by load torque and a dynamic torque $J\,(d\omega_m/dt)$. This torque component is known as dynamic torque as it is only present during the transient operations. From this equation, we can determine whether the drive is accelerating or decelerating. Such as during accelerating motor supplies load torque and additional torque component essentially. So, the torque, balancing the dynamics of electrical braking is very helpful.

Multiple-Choice Questions

1. The systems employ for the motion control manually
   (a) Automatic control drives
   (b) Semi-automatic drives
   (c) Manual control drives
   (d) All of the above

2. Belt drives is an example of the system
   (a) Electrical system
   (b) Mechanical system
   (c) Automation system
   (d) Both (b) & (c)
3. There are not the type of drives
   (a) Computer
   (b) Robotics
   (c) Car
   (d) Electric train
4. The drive which operates on many machines can be controlled by a large number of motors
   (a) Group drive
   (b) Individual drive
   (c) Multi-motor drive
   (d) All the above
5. A motor of less than full load power rating can be used if the load is:
   (a) Continuous duty
   (b) Short time duty
   (c) Intermittent periodic duty
   (d) None of these
6. The consideration involved in the selection of the type of electric drive for a particular application depends on
   (a) Speed control range and its nature
   (b) Starting torque
   (c) Environmental conditions
   (d) All of the above

Answers

1. (c) 2. (d) 3. (a) 4. (a) 5. (b)
6. (d)

Exercise

1. Define drives and their classification.
2. What are variable speed drives?
3. Specify five examples of drive systems.
4. Write a short note on motion control system.
5. Comparison between the individual drive and multi-motor drive.
6. What are the advantages of adjustable speed drive?
7. Write an application of drives.
8. Describe the factors affecting the selection of drives.
9. Give characteristics of manual, semi-automatic and automatic drives.
10. What are the choices of drives?
11. Describe load equalization with a mathematical expression.