Preface

The control of electrical machines very much depends on the context and environment in which motors are considered. How a machine is used has a strong influence on its control laws. These are especially related to loading characteristics, variables requiring control, operating conditions and, consequently, to the models chosen.

Loading intrinsically governs the choice of control laws and the way they are implemented. Common load torques are inertia torques, whether they are constant or variable, or possibly even randomly variable. Constant inertia torques are induced by rotating masses, which may be either symmetric homogenous, working as inertia flywheels, or dissymmetric heterogenous, causing torque fluctuations or vibrations. Inertia may vary due to a load geometrical distortion, as is the case in Watt regulators or hinged jibs, or to a change in the rotating mass, like in a winder.

Generally, non-inertial load torques need to be considered on top of these. Gravity causes load torques that adds up to the inertia torques induced by movement, especially in handling devices. The viscosity of the ambient environment causes resisting torques proportional to speed (viscous friction torques). This is the case in fans, boat propellers and more generally in all lubricated devices such as main bearings. Dry frictions cause stress, determined by the surface roughness of materials in contact and by the traverse speed. Being highly complex to model, stress is tricky to take into account in equations. The result of this is ill-controlled torques as well as inaccurate positioning.

Load driving by electrical motors is almost always operated through a transmission, the role of which is either to modify the range of accessible speeds and torques or to change the nature of the movement (rotation/translation). These transmitters alter the properties of loads quite significantly: not only do they adversely affect the order of magnitude of torques, but they also input nonlinearities that may compromise the operation of the system.

This is why this work starts with a presentation of the main problems encountered in mechanical transmissions, which are covered by Chapters 1, 2 and 3.

Chapters 4, 5, 6, 7 and 8 deal with the means available to drive a "converter/motor/transmission/load" unit. It intends to provide the reader the most useful and recent information on the techniques that make it possible to design the most accurate control laws for the problem that needs to be solved.

Generally, in usual applications, we strive to control three mechanical variables: velocity, position or torque (separately or simultaneously). Therefore, automatic techniques are called for. Even though usual linear controls (continuous or discrete, IPD, etc.) are still frequently used (rightly, considering their benefits), more recent and effective methods in difficult cases can be implemented. Optimal controls (linear-quadratic, linear-quadratic-Gaussian, etc.), adaptive controls (with or without the reference model), sliding mode controls or "bang-bang" controls help lead to more satisfying solutions, but often necessitate more comprehensive and more detailed models than linear control. Predictive controls, neural network and fuzzy logic controls help refine the control and improve the performance of dynamic system controls when the models are fairly unknown.

Finally, since the models used in electrical machine control involve several disciplines (automatic control, electrical engineering, computer science and mechanics), a common representation mode appears to be appropriate. Bond graphs fulfill this role perfectly and can be very helpful as useful tools for control. This topic will not be addressed here, since a specialized piece of work of more than 300 pages[1] fully covers this issue.

Control and model building are only applicable with accurate numeric values of parameters. Therefore, identification, applied to electrical machines, aims at providing these data. Although numerous methods of measurement make it possible to reach some variables, the majority of the models used in control reveal constants, which gather several electrical variables and are not directly measurable as a consequence. Moreover, the necessary values are dynamic values, which are impossible to obtain using traditional measurements. That is why a chapter is dedicated to the identification methods that are best adapted for our scope of activity.

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1 Karnopp D., Margolis D., Rosenberg R. *Systems Dynamic Modeling and Simulation of Mechatronic Systems*, John Wiley & Sons, 2000; and Geneviève Dauphin-Tanguy, *Les Bond Graph*, Hermes Science Publications, 2000.

The correct operation of the electrical machine is a key factor for operating safety. This work tackles the subject through the diagnosis of the defects of the machine. This technique is based on the continuous identification of the system and on the monitoring of the variation of its parameters. Diagnosis and adaptive control are sectors in which identification techniques are paramount.

Control techniques call upon traditional concepts in automatic control, such as stability, robustness and observers. The latter are essential to make use of some variables which are not accessible to measurement. However, such basic concepts are beyond the scope of this work. Indeed, developing them would require several chapters, the material of which could be found elsewhere, resulting in a global loss of generality and an unbalanced overview, with no obvious added value.

Chapters 9, 10 and 11 relate to the control of systems animated by a set of electrical motors, which requires a coordination of the actions of each component. Each motor obeys by the same control laws as those that would be applied to it if considered separately; however, a coordination (subsequently a coupling) between motors is introduced at the set point-level. Allowing complex operations such as deformations of the curvature of large areas, simultaneous machining, movements of hinged jibs or variable geometry openings requires the introduction of several coordination modes.

The most obvious is synchronization, which is a coordination based on time. Synchronization requires specific speeds or motions for each motor at certain times. The individual control laws of each actuator are thus coupled, either in a discrete way by an assignation method or in a continuous way when the durations of actions are imposed by the operating constraints of the system.

Position is also a coupling variable in multi-motor systems. The set point given to one of them will interfere with those of the other motors. Such is the case, for instance, with the variable geometry openings used in medicine for the irradiation of tumours. The VLT (Very Large Telescope) is also an example, with its huge mirrors deforming under their own weight. They are placed on multiple small electrical jacks, which correct the radius of curvature very precisely, requiring the coupling in position of 1,000 motors.

Finally, speed is also a coordination means for the control of a set of motors. Thus, on the machine tools (and many other devices), the feed and rotation speeds of pins are not independent and must be coordinated, like positions. This type of coordination also exists in assembly lines and conveying attachments: in such contexts, the velocity variations of a conveying belt must be reflected on all the others.

Working out a general theory at this level is a difficult task, that's why the third part of the work rather presents examples of multi-motors systems illustrating the main coordination types. Coordination by time: the robot, coordination by the position: the multileaf collimator, coordination by speed: the machine tools.

Throughout this work, our main goal has been to explain the concepts covered in a way understandable to most readers. This book is especially dedicated to people faced with issues at the border of their area of expertise. We hope that the material presented here will help them to solve these problems and gain a better view of global complex system design. Our purpose has therefore been twofold: providing a tool allowing better communication between experts from different domains, while allowing engineers from any background to gain a broader insight into general scientific culture.

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