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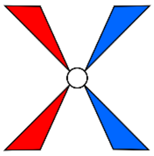
<tr><td><1338/c></td><td>the phase winding. The factor k is a parameter of the motor and depends on the ratio of the magnet flux linking the phase winding to the flux linkages brought about by the winding current. Typical values of k are in the range 0 25-1.0. A similar result to Eqn. (4.12) also applies to variable-reluctance motors, except that the parameter k has a different definition. Although the optimum phase resistance can be calculated, in practice it is a fairly simple matter to determine the optimum experimentally. The single.step response can be examined over a range of forcing resistance values (with appropriate changes of supply voltage to maintain constant phase current) until a suitable response is obtained. The discussion has centred on the two-phase hybrid motor, but electromagnetic damping can be produced in all types of motor provided more than one phase is excited when the rotor is settling to the equilibrium position. In some cases the electromagnetic damping effect can be enhanced by introducing a d.c. bias to all phases of the motor (Tal and Konecny, 1980). More recently Jones and Finch (1983) have shown that the single-step response can be optimised by allowing the phase winding currents to change gradually. As with the VCID, the design of a system for good damping using electromagnetic methods is often in direct conflict with the demands of high-speed operation. In the next Chapter, for example, it is shown that the system requires a large forcing resistance to operate at the highest speeds and in most cases the total phase resistance is then much greater than the optimum for electromagnetic damping. The system designer is therefore left to make a compromise choice of forcing resistance according to the application. High-speed operation 5.1 Introduction In many applications the motor must be able to produce a large Pull-out torque over a wide range of stepping rates, so the time taken to position a load is minimised. For example, suppose a motor with the torque/speed characteristic shown in Fig.5.l has to move a load 1000 steps. If the load torque is 0.5 Nm then the pull-out rate is 500 steps per second and the load is positioned in approximately 1000/500 = 2 seconds. However for a load torque of 1 Nm the maximum speed would have to be restricted to 200 steps per second and the positioning time would be 1000/200 = 5 seconds. Clearly the designer of the system with a load torque of 1 Nm would like to know what parameters of the motor and drive need to be changed so that a pull.out torque of 1 Nm is available at 500 steps per second. At high stepping rates each phase is excited for only a short time interval and the build.up time of the phase current is</td></tr>
<tr><td rowspan="2">
Key:
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<tr><td>. When a motor is operating at the highest speeds the current in each phase may not even reach its rated value before the excitation interval finishes and the phase is turned off. In addition the time taken for the phase current to decay becomes important at high speeds, because the phase current continues flowing (through the freewheeling diode) beyond the excitation interval dictated by the drive transistor switch. Consequently the pull-out torque falls with increasing stepping rate for two basic reasons: (a) the phase currents are lower, so the motor</td></tr>
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	torque produced at any rotor position is reduced, (b) phase currents may flow at rotor positions which produce a negative phase torque. A quantitative treatment of these effects for both hybrid and variable-reluctance motors is presented in this chapter. The calculation of pull-out torque at high speeds is complicated by the variations in current during the excitation time of each phase, which means that there is no longer a simple relationship between the static torque/rotor position characteristic and the pull-out torque. Typical phase current waveforms for one-phase-on unipolar excitation of a three.phase variable -reluctance motor are shown in Fig.5.2. At the lowest operating speeds [Fig.s.2 (a)] the current waveforms are nearly rectangular, the build-up of current to the rated level occupies a minor portion of the excitation time and the methods of Chapter 4 can be used to calculate the pull-out torque. For stepping rates where the phase is only excited for a time similar to the winding time constant, however, the wave form [Fig.5.2(b)] is considerably distorted by the nearly exponential rise and decay of the phase current. At very high operating speeds the voltage induced in the phase windings by the rotor motion must also be considered. The effect of these induced voltages can be seen in the high-speed waveform of Fig.5.2(c), in which the waveform can no longer be described in terms of a simple exponential rise and decay. Even while the phase is switched on it is possible for the current to be reduced by the induced voltage, which is at its maximum positive value when the phase is excited. Similarly when the phase is turned off the decay of current can be temporarily reversed as the induced voltage passes through its maximum negative value. Therefore analysis of the complete pull-out torque/speed characteristics must include the effects of voltages induced in tile windings by the moving rotor. In most stepping motor systems the winding time constant is much less than the period of rotor oscillations about each equilibrium position. At the stepping rates considered in this Chapter we are justified in regarding the rotor velocity as constant; the system inertia is sufficient to maintain a steady speed, even if the motor torque varies