about 95 percent synchronous speed at full load. Overloads decrease the speed further until the maximum torque point is reached. If the load torque exceeds this point the motor will stall. The motor torque varies as the square of the voltage. If the voltage drops 10 percent, the motor torque will be only 81 percent of rated value. Both power factor and efficiency are improved if the motor is operating as near rated load as possible. In addition, as shown in Fig. 2, power factor and efficiency are better for higher speed motors.

Wound Rotor motors are used for applications requiring high starting torque at low starting current, because a wound rotor motor with its controller and resistance can develop full load torque when starting with about full load current. For comparison, a squirrel-cage motor would require from 3 to 5 times as much current to develop full load torque at starting. The wound rotor motor is also used for varying speed service to drive fans, blowers, and other continuous duty apparatus.

The addition of resistance to the secondary winding of the wound rotor motor changes the speed torque characteristics. The motor speed, with

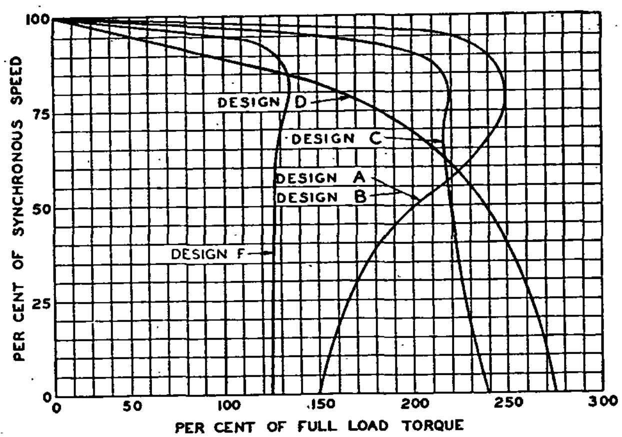

Fig. 1. Speed Torque Characteristics of Squirrel-Cage Motors

the resistance added, is dependent on load, and consequently, the motor has very poor speed regulation when secondary resistance is added to reduce the speed to values below 50 percent. Fig. 3 illustrates the characteristics of wound rotor motors.

Synchronous motors are used for continuous duty applications at constant speed where efficiency and power factor are important. Another advantage of these motors is that of lower initial cost in large sizes and for low speeds when compared with squirrel-cage type motors.

The outstanding advantage of the synchronous motor is that its power factor can be changed to compensate for the low power factor of other drives in the same location. Lagging power factor is an inherent characteristic of all induction apparatus, such as induction motors and neon signs. Unless synchronous motors or capacitors are installed, the plant power factor may be comparatively low. This does not necessarily mean that corrective equipment must always be installed, but in most cases it

is desirable to determine what advantages may be gained by improving the power factor. With purchased power, if the rates include a clause embodying a penalty for low power factor, or a bonus for high power factor, the saving in power costs may often make a very good return on the investment required for the corrective equipment.

Synchronous motors are used to drive fans, blowers, pumps, compressors and other applications. Compressor applications having a high peak torque require the use of flywheels to smooth out power peaks, and should always be referred to the electrical manufacturer for recommendations.

Synchronous motors are provided with built-in damper windings on the rotor and operate during the starting period similarly to squirrel-cage

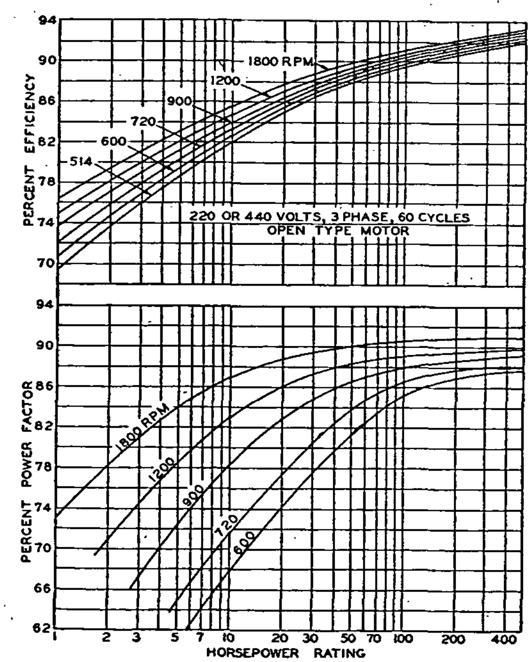

Fig. 2. Efficiencies and Power Factors for Squirrel-Cage Induction Motors

motors. After the motor is nearly up to speed, field excitation is applied and the motor draws into step at synchronous speed. After excitation is applied, the motor runs at exactly constant speed and will remain at this speed until a load approaching the pull-out load is reached, whereupon the motor pulls out of synchronism and stops.

In applying synchronous motors consideration must be given to the torque the motor can develop on pull-in, that is, at the instant when field excitation is applied. Table 5 shows typical application requirements of synchronous motor drives, listing starting, pull-in, and pull-out torques.

Multi-Speed motors provide flexibility in many types of drives. Synchronous motors can be furnished only with a 2 to 1 ratio in speed, single