Synchronization and Speed Control of Synchronized Sound Pictures [1]

By H. M. STOLLER

SYNOPSIS: The reproduction of the synchronized sound picture of today presents no serious problem of synchronization, for this factor has been practically eliminated by the perfection of electrical means for reproducing sound with equipment which may be coupled mechanically to the picture projector.

The important problem of the present day, in connection with the reproduction of synchronized sound pictures, is the provision of suitable means for maintaining a constant speed of the sound reproducing mechanism in order that the pitch of the sound being reproduced may not suffer any sudden change which would be sensed by a good musical ear. Control circuits using vacuum tubes with a frequency bridge as a speed standard with provision for manual variable speed control are described and explained for use with both A.C. and D.C. motors. Remote synchronization permitting the recording of pictures and sound simultaneously on equipment located some distance apart is obtained by a modification of the Michalke electric gear system.

WHEN Thomas A. Edison gave a demonstration of his talking motion pictures nearly sixteen years ago one of his chief problems was proper synchronization between his acoustic phonograph and the motion picture projector. It was then necessary to locate the phonograph behind the screen in order to make the sound appear to come from the picture. A system of belts and pulleys running from one end of the theater to the other was used to secure synchronization with the projector in the booth.

The development of the electrical reproducer has made it possible to locate the turntable and reproducing mechanism in the projection booth permitting a direct mechanical coupling between it and the projector. The horns are located behind the screen and electrically connected by wires with the electrical reproducer.

Thus there is no problem of synchronization in reproducing except to set the needle on the disc at the proper point before starting. However, such mechanical coupling between the projector and sound recorder (either of the disc or film type) makes it necessary to provide very close speed regulation on the projector motor, since variations in speed produce proportional changes in the pitch of the sound.

This paper will describe the speed regulating system employed in reproducing and the synchronization system used in recording.

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SPEED REGULATION REQUIREMENTS

A good musical ear while having a sense of absolute pitch of only about 3 per cent is extremely sensitive to sudden changes in pitch. It has been found that a sudden change in pitch as small as one half of 1 per cent may be noticed if made abruptly. In order to properly take care of this requirement, therefore, the speed regulation or change in speed of the motor drive over normal variations in line voltage and load should be held within 2/10 of 1 per cent.

The absolute speed must also be held near these limits since at the end of a film it is necessary to switch from one projector to another with minimum change in the pitch of the sound reproduction.

VOLTAGE, FREQUENCY AND LOAD VARIATIONS

A study of the voltage variations in power supply systems indicated a range from 100 to 125 volts. At a particular location the normal variation of voltage was found to be 5 per cent above or below the mean value with occasional momentary variations of as much as 10 per cent above and below mean value.

An investigation of variations in frequency of the supply voltage showed that in the large cities the frequency was held very accurately at 60 cycles. In New York City for example the frequency stays within one quarter of 1 cycle and does not change rapidly. However, in some small power systems the frequency varied as much as 5 cycles and in some cases was subject to rapid changes in frequency.

The load of the motor is due mainly to mechanical friction in the projector and take-up mechanism. This load was found to be on the average 1/10 of a horse power but subject to wide variations. In the case of a new machine with a stiff adjustment of the take-up mechanism, the load was found to be as high as one-fifth of a horse power.

SPEED CONTROL CIRCUIT

A consideration of the variables just discussed imposes rather severe requirements of speed control, the two extremes being (1) the combination of low line voltage, low frequency and heavy load, (2) the combination of high line voltage, high frequency and light load. Ordinarily it might be possible to compromise and not provide for such an extremely unfavorable combination of requirements. However, it must be borne in mind that in the case of a musical program the failure of the speed regulating system for even as short a time as a fraction of a second would be a very serious matter causing the music to sound off pitch similar to a phonograph which has run down while in operation.

An examination of the standard commercial types of speed control indicated that there was nothing exactly suitable. The nearest approach to a suitable governor is the standard type of phonograph governor but this friction brake type of governor has serious objections if applied to a motor of considerable power output. In order, therefore, to have a control system which would be free from maintenance, it was necessary to develop a special form of control system for the purpose. Fig. 1 shows a photograph of the A.C. motor and its control cabinet.

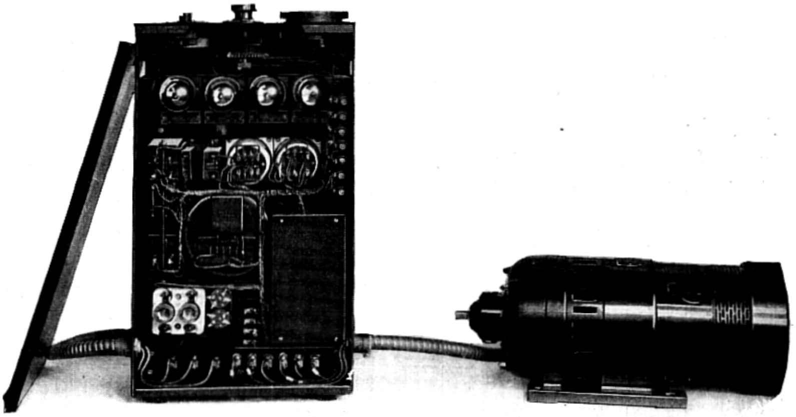

Fig. 1—A. C. Motor with control cabinet.

A.C. Motor Control Circuit

Fig. 2 shows the A.C. motor circuit which consists of a repulsion type of motor coupled to a small auxiliary alternator providing a frequency of 720 cycles which through a control circuit is made to operate a variable reactor across the armature terminals of the motor. If the speed of the motor is too high, the control circuit produces a maximum impedance in the reactor L_1 thereby reducing the armature current of the motor and causing it to slow down. While if the speed is too low the control circuit causes the reactor L_1 to have a minimum of impedance increasing the armature current and causing the motor to speed up.

This reactor L_1 is of the D.C. saturating type having two outer legs with A.C. windings and the middle leg with a D.C. winding. The A.C. flux circulates around the two outer legs. The D.C. flux flows from the middle leg and returns through the outer legs in parallel. When D.C. flux is sent through the middle leg it saturates the outer legs thereby reducing their impedance to A.C. This type of reactance is old and was employed by Alexanderson as a magnetic modulator in his early radio work.

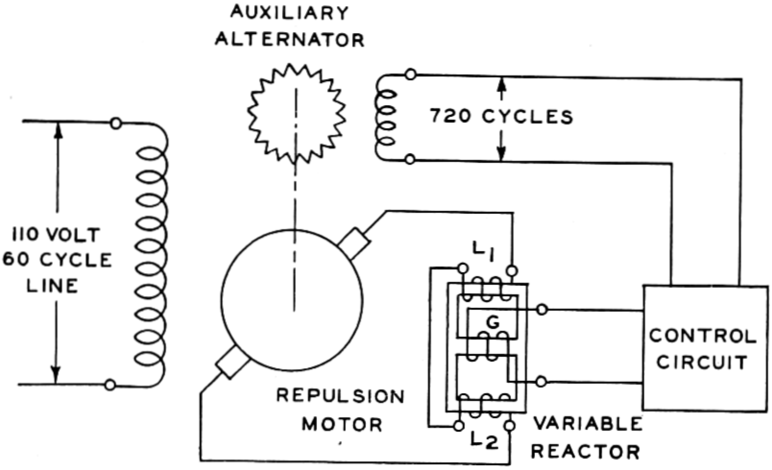

Fig. 2—A. C. Motor circuit diagram.

Fig. 3 shows one element of the speed control circuit. This consists of a bridge circuit having one variable arm and three fixed arms. The variable arm comprises a tuned circuit consisting of the inductance L and the capacity C which are designed to tune at exactly the frequency corresponding to the desired motor speed. When this circuit is in tune it has a resistive impedance which is balanced by the fixed arm R of the bridge. The other two fixed arms on the left

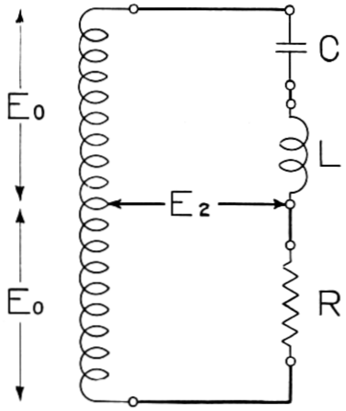

Fig. 3—Bridge circuit in speed control system.

are windings of a transformer with a mid tap. If a voltage $2E_0$ having a frequency of 720 cycles (which is the frequency corresponding to the desired speed of 1,200 R.P.M.) is supplied to the bridge it will be apparent that the output voltage E_2 will be zero. If, however, the speed is low the tuned circuit will have a condensive reactance while if the speed is high it will have an inductive reactance. The output voltage E_2 will, therefore, change abruptly 180 electrical degrees from a speed below 1,200 to a speed above 1,200. This characteristic is shown in Fig. 4.

The use of the above described bridge circuit gives a very sharp characteristic due to the fact that the effective resistance component of the tuned circuit is balanced out by the adjacent resistance arm of the bridge. In this way an overall characteristic of the desired sharpness is secured using a comparatively small and inexpensive coil and condenser.

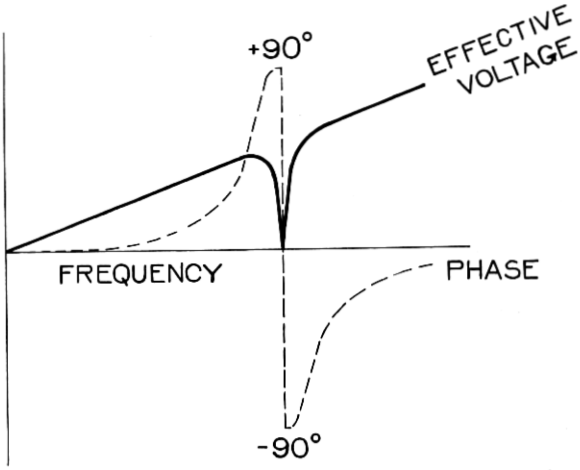

Fig. 4—Output voltage characteristic of bridge circuit.

Fig. 5 shows the complete control circuit. The output from the bridge circuit is supplied to the grid of tube V_4 which is called the detector tube. The plate voltage of this tube comes from the 720-cycle generator through the step-up transformer T_4. The phase of this voltage, therefore, remains constant. The phase angle of the grid voltage, however, comes from the bridge output circuit through the step-up transformer T_3 and as previously explained suffers a sudden reversal of phase as the speed passes through 1,200 R.P.M. Fig. 6 shows the resulting current characteristic through tube V_4. This current flows through coupling resistance R_1 which drives the grids of tubes V_1 and V_2 negative. This in turn reduces the plate current through tubes V_1 and V_2 and hence through the D.C. winding of the inductance L_1 controlling the armature current of the motor.

Tube V_3 is a rectifier tube supplying excitation to the field of the 720-cycle alternator and the negative "C" voltage along potentiometer P_1.

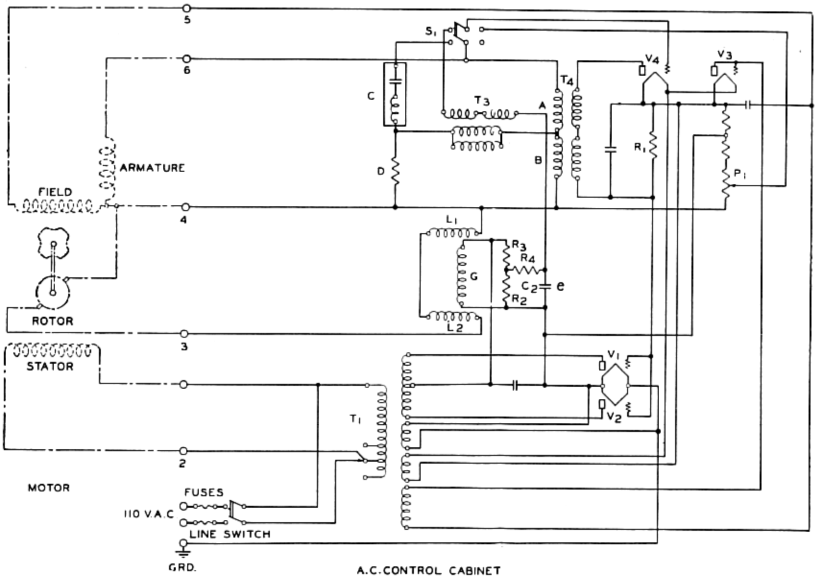

Fig. 5—A. C. control circuit diagram.

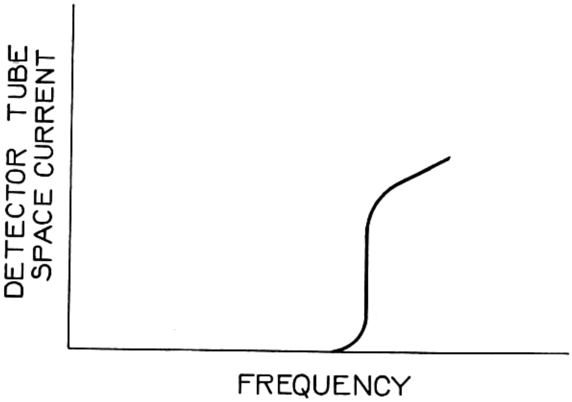

Fig. 6—Characteristic of space current through detector tube V_4.

Fig. 7 shows the performance characteristics of the motor. It will be noted that the actual speed characteristic is practically flat. This flat characteristic is secured by a compensating network consisting of the resistances R_2, R_3 and R_4 and the condenser C_2. This compensating network feeds back on the grid of tube V_4 a portion of the voltage drop across the D.C. winding of inductance L_1 thereby correcting for the "static fluctuation" of the control circuit. By a suitable adjustment of this compensating resistance the control circuit may be arranged to give flat regulation, under regulation or even over regulation if desired. Fig. 7 has been drawn with line voltage as the variable. A similar characteristic is also obtained with load as the variable instead of voltage.

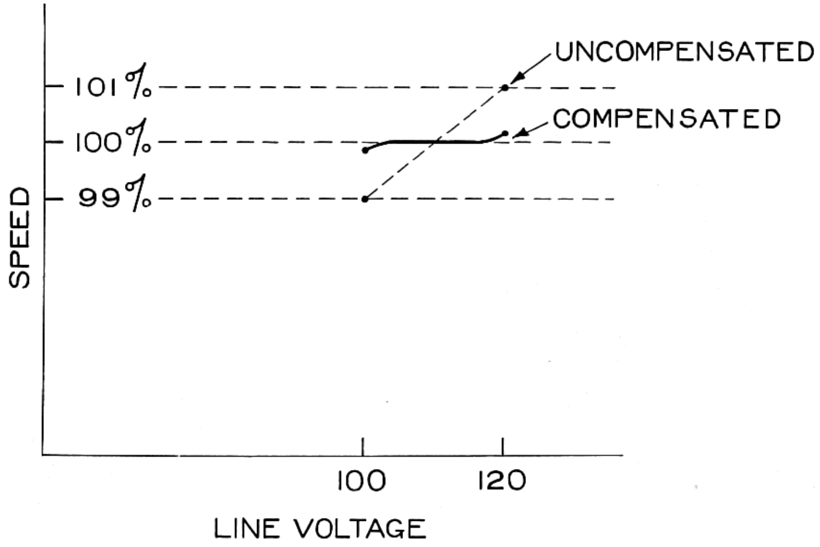

Fig. 7—Performance characteristics of motor.

An interesting point in connection with this compensation circuit is the necessity for avoiding hunting or surging of the speed. It is a well-known property of all forms of governors that if they are adjusted to too great a sensitivity the speed instead of remaining constant will fluctuate up and down about a mean value. The simplest method of preventing such speed fluctuations is to decrease the sensitivity of the governor allowing a bigger change in speed with load (or voltage) and then compensating for this change of speed or "static fluctuation" by means of a delayed action compensator. This phenomenon is well-known in the mechanical governor art and is described by Trinks in his book "Governors and the Governing of Prime Movers." The electrical equivalent of this mechanical system is obtained by introducing the condenser C_2 in series with the high resistance R_4. When a change in current through the regulating reactance L_1 occurs the corresponding change in voltage drop is not transmitted to the condenser C_2 immediately, but C_2 changes its voltage after a certain time lag (approximately 1 second), required to charge the condenser through the resistance R_4. The introduction of this time lag restores the precision of the circuit to the flat characteristic desired without introducing hunting.

Variable Speed Operation

By throwing the switch S_1 to the right the operator can disconnect the tuned circuit control and substitute a potentiometer P_1 as a source of grid voltage for tube V_4. By means of this potentiometer the operator can adjust the speed of the motor at any speed from 900 to 1,500 R.P.M. corresponding to 68 to 112 feet of film per minute. This feature is employed for ordinary motion picture work where it is unnecessary to synchronize the picture with the sound. The regulation of the circuit under these conditions is sufficiently good for ordinary motion pictures.

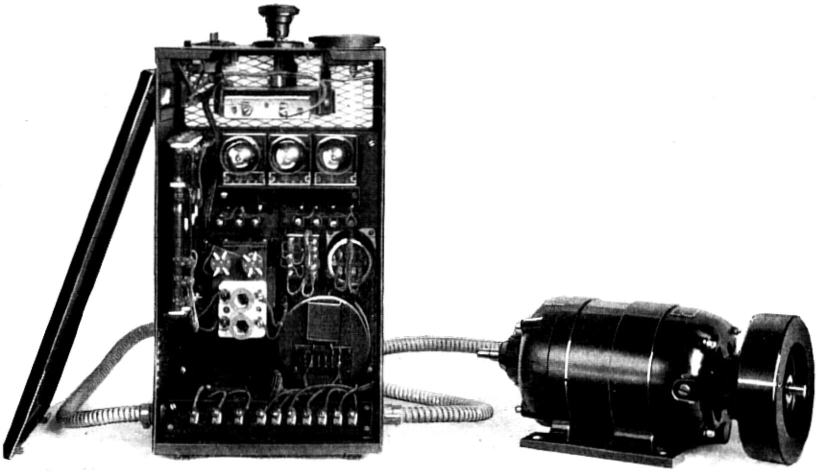

Fig. 8—D. C. motor with control cabinet.

An interesting feature in this connection is that theaters in many cases have preferred to use the regulated speed position for ordinary motion pictures as well as synchronized pictures. The reason for this being that with the speed of the projector precisely controlled the orchestra leader is better able to keep his orchestra in step with the picture indicating apparently that closer speed regulation than is at present provided would be desirable for ordinary motion pictures as well as synchronized pictures.

D.C. Control Circuit

A circuit very similar to the one just described is employed in the case of the D.C. motor. Fig. 8 shows a photograph of this motor and its control cabinet. The circuit is shown in Fig. 9. It differs from the A.C. circuit in that an auxiliary regulating field winding is employed on the motor instead of a variable reactor. The source of power for the plates of the vacuum tubes is obtained from the auxiliary 720-cycle generator instead of from a 60-cycle transformer as in the A.C. circuit. Since a strengthening of the field of the D.C. motor is required in order to reduce the speed it is necessary to reverse the phase relationship of the transformer T_1, so that the current in the detector tube decreases at speeds above 1,200 instead of increasing as in the case of the A.C. circuit.

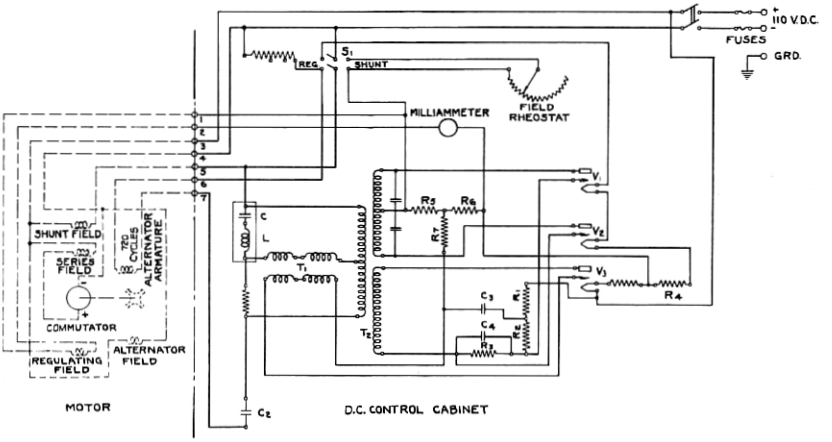

Fig. 9—D. C. control circuit diagram.

The operation of the circuit is as follows: When the line switch is first thrown the motor acts as an ordinary D.C. shunt motor and accelerates. At low speeds the output from the 720-cycle generator is low and consequently there is no plate voltage supplied to the tubes and no current through the auxiliary field winding. The field is, therefore, weak and the motor speeds up. This condition is maintained until the equilibrium speed of 1,200 R.P.M. is approached. The phase angle of the voltage supplied to the grid of the tube V_3 is then in phase with the voltage supplied to the plate so that the grid of the tube goes positive at the same time that the plate is positive.

This causes a current to flow through the coupling resistances R_1 and R_2 which drives the grids of tubes V_1 and V_2 negative, thereby keeping down the current through these tubes and hence maintaining a weak motor field. The motor, therefore, continues to accelerate until a speed of 1,200 R.P.M. is reached. At this point as previously explained under the description of the bridge circuit, the phase of the output suddenly reverses whereupon the grid of the detector tube goes negative at the same time that the plate goes positive, thereby cutting off the current through the detector tube V_3 and reducing the negative C voltage on the grids of tubes V_1 and V_2. This increases the plate current through the regulating field thereby stiffening the field of the motor and checking its rise in speed. In practice the current through the detector tube is neither at one extreme nor the other but reaches an equilibrium at the speed of 1,200 R.P.M. A feedback network having the delay feature for prevention of hunting is included in the same manner as previously described for the A.C. circuit. The characteristic curves for the D.C. motor are similar to those shown in Fig. 7 for the A.C. motor.

For the operation of ordinary motion pictures the motor is changed to a simple shunt D.C. motor by the switch S_1 and the speed varied by means of the field rheostat.

Motor Drive of Recording System

It might appear that the simplest method of securing synchronization in recording work would also be mechanical connection between the recording machine and the camera. It has been found desirable, however, from a practical standpoint to have the camera movable with respect to the recording machine as the recorder has to be accurately lined up and adjusted and is not essentially a portable machine whereas the camera in ordinary motion picture work must be a portable piece of equipment. It has been necessary, therefore, to develop a motor drive equipment which will satisfactorily interlock the camera and the recording machine but leave the camera unit portable. It is essential that the interlock should hold not only during normal conditions but during acceleration and deceleration. In other words, the system must be the full equivalent of a mechanically geared system. The principle employed is old being disclosed in a patent issued to Michalke in 1901. In Fig. 10, A and B are two units which it is desired to interlock. Each unit has a three phase stator and a three phase rotor, the latter provided with slip rings. Magnetizing current for the system is supplied from an independent three phase, 60-cycle source. If the rotors of A and B are in exactly the same positions with respect to the stators it is evident that the e.m.f.'s produced in them by transformer action will be identical as to voltage and phase. Consequently there will be no flow of current over the rotor leads and hence no torque developed. If, however, unit *A* is turned through a small angle then the phase of the e.m.f.'s produced in the rotor circuits will differ from that in *B* and a current will flow in the rotor circuits producing a torque which will tend to make unit *B* assume the same position as *A*. If *A* is rotated continuously *B* will follow it up to synchronous speed of the stator field at which point the torque will drop to zero since no e.m.f. is induced in the rotor of either machine.

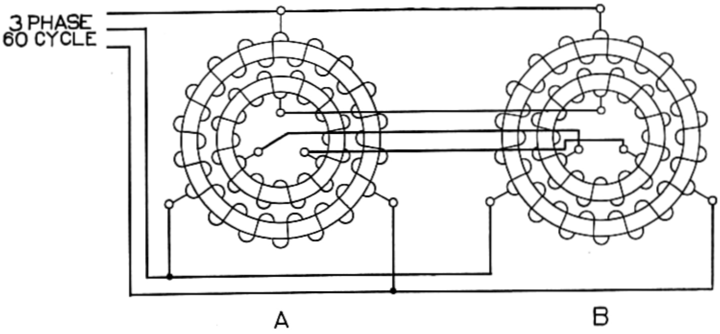

Fig. 10—Electrical driving gear.

Complete Recording Circuit

The portion of the circuit shown in Fig. 10, is merely the equivalent of a mechanical gear, neither unit tending to rotate as a motor by itself. In order to produce such rotation, therefore, a distributor set is added as shown in Fig. 11, the distributor acting, to use a mechanical analogy, as the driving gear of the system and each of the individual units of the system as driven gears. The distributor is itself driven by a D.C. motor provided with the speed control circuit previously described and shown in Fig. 9. The speed of the system is thus solely dependent on the D.C. driving motor and independent of the 60-cycle excitation frequency.

In practice the system is controlled by an operator at the distributor set and by means of switches any desired number of cameras, recording machines, or projectors may be employed. The projecting machines are used in case it is desired to make up a sound record to accompany an ordinary motion picture film which has previously been recorded without sound accompaniment. It has been found that the system operates very satisfactorily and requires very little maintenance.

When starting up for the first time it is necessary that the various units should line up properly as to phase otherwise there will be a local flow of current in the rotor circuits, which will cause the motors to operate as induction motors and run away. Under running conditions the system is very stable showing no tendency to hunt or surge between units, for the reason that being polyphase each phase as it becomes inactive (when the induced e.m.f. passes through zero) acts as a damping winding for the other two active phases.

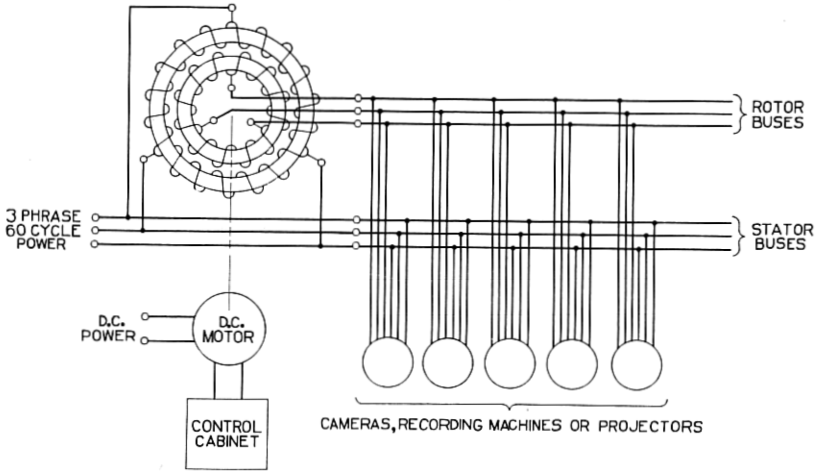

Fig. 11—Diagram of synchronizing system for recording.

If the load on a particular unit of this system is varied there will be a variation in the phase angle between this unit and other parts of the system in the same manner as in the case of a synchronous motor of the ordinary type. The magnitude of this phase angle, however, does not vary more than 30 electrical degrees or 15 mechanical degrees and is sufficiently small so that it produces an inappreciable effect on the synchronization.

Discussion

The above described motor equipment with its associated control circuits has been in practical use for over a year both in recording and reproducing work and there have been practically no troubles in service.

In the design of this equipment, first consideration has been given to its precision and reliability in operation and the provision of adequate margins to care for all variations in service conditions. As a result it has been possible to maintain a high standard of quality in music and speech reproduction.