Synchronization System for Two-Way Television *

By H. M. STOLLER

In a previous paper presented before the June, 1927 Convention of the American Institute of Electrical Engineers, the method of securing synchronization of television signals was described as employed in the Bell System Television demonstration of April, 1927. The present paper describes the development of a new control circuit which is in use in the new two-way television system between the Bell Telephone Laboratories at 463 West Street and the American Telephone and Telegraph Company building at 195 Broadway, New York.

TELEVISION transmission requires not only synchronization of the transmitting and receiving equipment but such synchronization must be held to a narrow phase angle so that the scanning discs at the transmitting and receiving end will never depart more than a small fraction of a picture frame width from the desired position.[1] In the 1927 demonstration, 2125 cycle synchronous motors were employed with supplementary D.C. motors to facilitate starting. This plan required the use of vacuum tube amplifiers of large size in order to supply sufficient power to the synchronous motors.

Such high frequency synchronous motors, however, are inefficient and expensive, so that when designing the new system, it was desired to solve the problem of synchronization with simpler and cheaper equipment and in a manner which would require less attention in starting. It was particularly desired to employ a motor which could be operated directly from the 110 volt lighting circuit without any auxiliary "A", "B" or "C" batteries for the control equipment.

Description of Motor

Figure 1 shows a photograph of the new television motor and its associated control equipment.

The motor is a four pole compound wound D.C. motor with the following special features added.

1. An auxiliary regulating field, the current through which is controlled by the vacuum tube regulator.
2. A damping winding on the face of the field poles to prevent the field flux from shifting (Fig. 3).

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[1] These requirements are more fully discussed in a previous paper. (*Journal of the A. I. E. E.*, Vol. 46, page 940, 1927.)

3. Three slip rings are provided at points 120 electrical degrees apart for furnishing three phase power to supply plate and filament voltage for the regulating circuit.
4. A pilot generator of the inductor type is built into the motor frame and delivers a frequency proportional to the motor speed for actuating the control circuit.

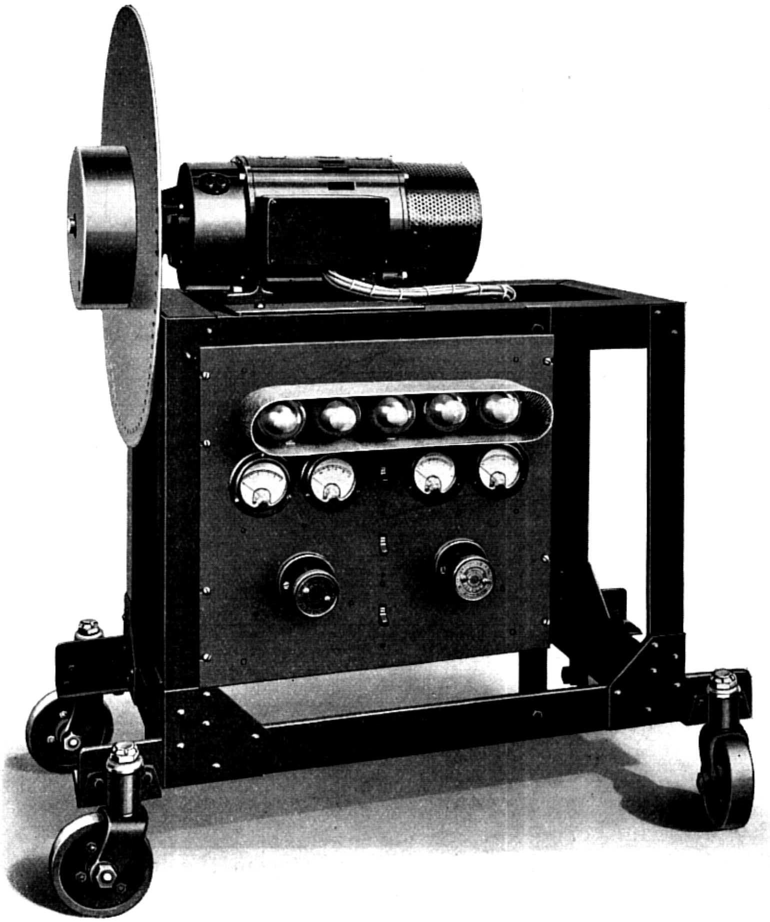

Fig. 1—New television motor and vacuum tube control circuit.

5. A hydraulically damped coupling is provided between the motor shaft and the scanning disc. (Fig. 4.)

The motor frame was made from a standard 36 tooth stator punching by cutting out three teeth per pole, thus forming four polar areas of six teeth each. The shunt, series and regulating fields enclose the entire polar areas. The damping winding consists of insulated closed turns of heavy copper wire distributed over the pole faces in the slots as shown in Fig. 3. It will be noted that this damping winding has no effect upon the flux through the poles as long as the flux density over the polar surface does not shift. In other words, the damping winding permits the total flux of the motor to increase or decrease as required by the regulating circuit but will oppose any tendency of the flux to shift back and forth across the pole face. As will be explained

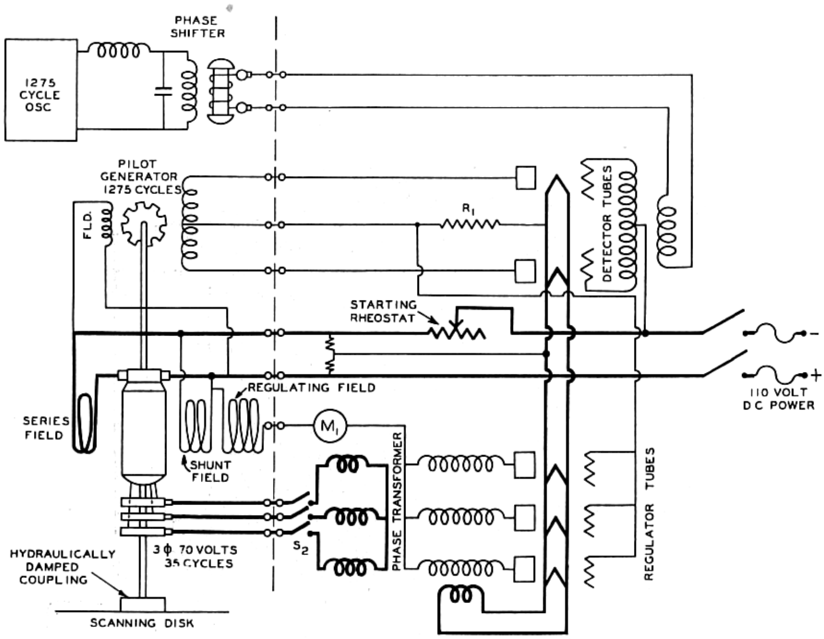

Fig. 2—Schematic diagram of control circuit.

later on, this feature is essential in order to prevent hunting or instability of the image.

The hydraulically damped coupling between the motor shaft and the scanning disc is also essential in order to avoid hunting. It employs flexible metal bellows filled with oil and connected by a small pipe equipped with a needle valve for adjusting the amount of damping. Figure 4 shows its construction. The scanning disc itself is centered on a ball bearing which allows the disc to rotate with respect to the shaft within approximately ± 5 degrees mechanical movement.

Control Circuit

Figure 2 shows a schematic diagram of the control circuit. When the motor is operating at full speed the pilot generator delivers approximately 1 watt of power at 300 volts, 1275 cycles to the plates of a pair of push-pull detector tubes. The grids of these tubes are supplied with an e.m.f. of the same frequency from an oscillator or other source of power having a sufficiently constant frequency. The amount of power required for this grid circuit is only a few thousandths of a watt. The detector tubes rectify the plate voltage producing a potential drop across the coupling resistance R_1. If the plate and grid voltages are in phase, so that the grids of the tubes are positive at the

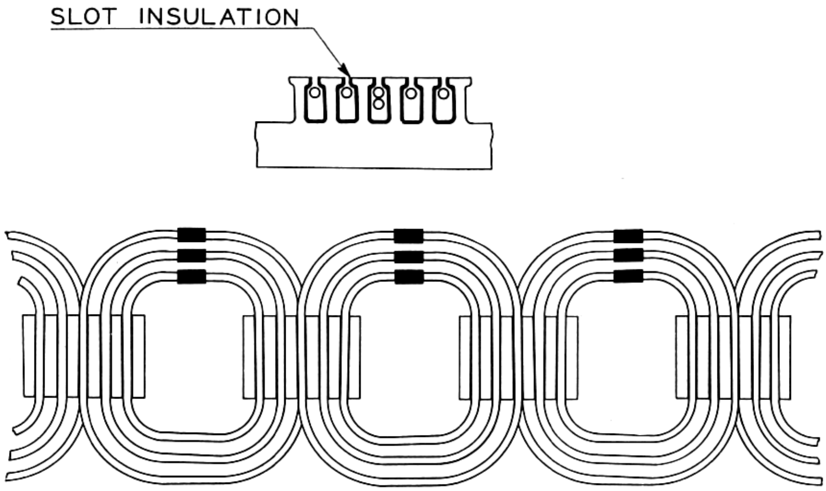

Fig. 3—Damping winding preventing shifting of field flux.

same instant that the plates are positive, the plate current will be a maximum. If the grid voltage is negative when the plate voltage is positive the plate current is practically zero, so that the magnitude of this current is a function of the phase relationship between the grid and plate voltages as shown in Fig. 5.

The voltage drop across the coupling resistance R_1 is applied to the grid circuits of three regulator tubes. These tubes derive their plate voltage supply from a three phase transformer fed with power from the three slip rings provided on the motor. These tubes act as a rectifier whose output is controlled by the potential impressed upon the grids from the coupling resistance R_1. The current of the regulator tubes is passed through the regulating field provided on the motor. This field is in a direction to aid the shunt field and series fields of the motor.

The operation of the circuit is as follows: In starting switch S_1 is closed which applies direct current to the shunt field and armature circuits of the motor. The motor accelerates as an ordinary compound wound motor. Switch S_2 is then closed applying three phase power from the slip rings of the motor to the transformer. As the speed of the motor approaches the operating point, the beat frequency between the pilot generator and the oscillator will cause beats in the current through the regulating field which are visible on the meter M_1. Let us assume that the field rheostat has been previously adjusted so that with

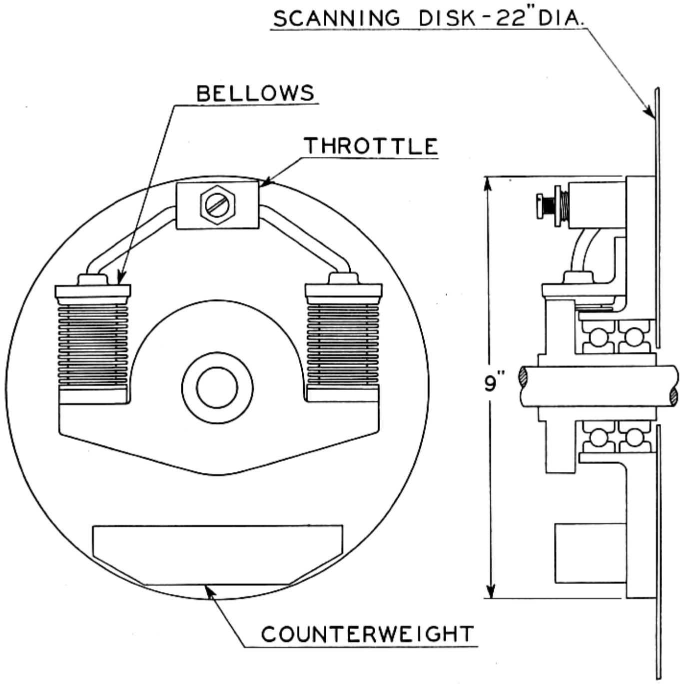

Fig. 4—Hydraulically damped coupling to prevent hunting of motor.

the shunt field alone the motor will tend to run slightly over the desired operating speed. When the exact operating speed is obtained, the beat frequency in the regulating field will be zero and as the motor tends to accelerate, the phase relationship between the pilot generator and the oscillator will reach a point tending to give maximum strength to the regulating field. When this point is reached, the acceleration of the motor will be checked by the increased field and the speed will tend to fall until the phase of the pilot generator with respect to the oscillator has shifted sufficiently so that the regulating field current is reduced to an equilibrium value, after which the motor continues to run at constant speed in accordance with the frequency of the oscillator.

Operating tests on the circuit show that the motor will hold in step over line voltage ranges from 100 to 125 volts and will be self-synchronizing over somewhat narrower voltage limits. Thus, under normal conditions all that is necessary from an operating standpoint is to close the switch and wait for the motor to pull into step.

Control Oscillator

The control oscillator is a standard type of vacuum tube oscillator having a frequency precision of the order of 1 part in 1000, when

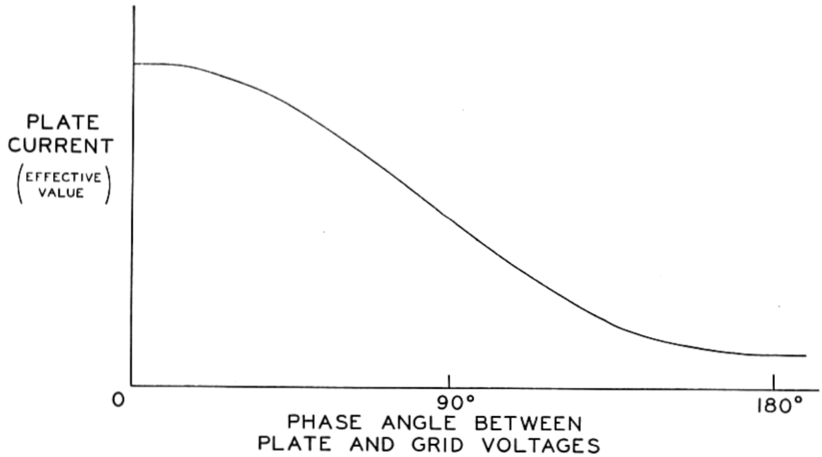

Fig. 5—Phase detector tube characteristic.

delivering the negligible output of .005 watts to the grid circuit of the detector tubes. This frequency is delivered directly to the motor circuits at one end of the line and is transmitted over a separate cable pair to the control circuits at the other end of the line. It was found that the detector tubes would operate successfully over a considerable variation in power level, provided the minimum oscillator output was sufficient.

An interesting alternative method was developed in which the synchronizing channel between stations may be omitted entirely, but this method was not used in the present system as the additional cost was not justified. The method, however, is described as it may prove of value if television transmission over long distances is considered.

Mr. W. A. Marrison in his paper "A High Precision Standard of Frequency," *Proceedings I. R. E.* July, 1929, described a crystal controlled oscillator which would maintain a precision as to frequency of 1 part in 10,000,000. This oscillator employs a quartz crystal as its primary means of control and by means of secondary circuits the natural period of the crystal, which is approximately 100,000 cycles, may be stepped down to lower frequencies which are more convenient for such purposes as motor control.

By this means, a frequency of the desired value may be obtained with a precision so great that the speed of the scanning discs under control of the above described circuit will be so nearly perfect that no synchronization channel at all is required. For example, if the period of observation of the television image is 5 minutes, the scanning disc will make 5300 revolutions when operating at a speed of 1060 r.p.m. Assuming a precision of control of 1 part in 10,000,000, the maximum error during the 5 minute interval will be 5300 divided by 10,000,000 or about 1/2000 of 1 revolution. Expressed in degrees on the periphery of the disc, this is equivalent to approximately 1/6 of 1 degree or since the width of the television image with 72 holes in the scanning disc is 5 degrees, the image will drift 1/30 of a frame width during the 5 minute interval. If the speed of the scanning disc at the other end drifts an equal amount in the opposite direction, the displacement of the television image will be only 1/15 of a frame width, which is a tolerable amount of drift.

From a practical viewpoint, however, it is apparent that the additional cost of very precise independent oscillators would be greater than the cost of providing the synchronization channel, except possibly for transmission over long distances.

Framing

Referring to Fig. 2, it will be noted that a phase shifter is provided between the oscillator and the input terminals to the control circuit. This phase shifter is designed with a split phase primary member producing a rotating magnetic field. The secondary member is single phase and is mounted on a shaft provided with a handle. By rotating the handle of the phase shifter in the desired direction, the frequency delivered from the phase shifter will be the algebraic sum of the frequencies of the oscillator plus the frequency of rotation of the armature of the phase shifter. It is, therefore, a simple matter for the operator at the receiving end to momentarily increase or decrease the control frequency and thus bring the picture into frame.

Discussion

During the development of the control system, one of the first difficulties encountered was hunting of the controlled motor. The problem of hunting, of course, becomes more difficult of solution the greater the precision of speed regulation desired and the greater the moment of inertia of the load connected to the motor, the latter statement applying only to controlled systems of the synchronous type. Since the moment of inertia of the scanning disc is large relative to that of the motor armature, it is seen that the conditions for securing stable rotation would be unfavorable in both the above mentioned respects if the scanning disc were mounted directly on the motor shaft. The hydraulically damped type of coupling above described was, therefore, inserted between the motor shaft and the scanning disc. It was found, however, that hunting still occurred. A further analysis of the problem showed that the axis of the field flux of the motor was shifting back and forth across the pole faces. The damping winding shown in Fig. 4 was then added with a marked improvement. It was also observed that a strong series field on the motor assisted in securing stability and it was, in fact, necessary to employ all three expedients to secure satisfactory performance. In the system as finally developed the television image, if disturbed by a momentary load such as the pressure of the hand against the disc, would come back to rest within approximately one second, there being two oscillations during this interval. In actual operation, it was found that the normal fluctuations in line voltage occurring on the commercial power supply produced no transients of sufficient magnitude to cause any objectional instability in the received image.

In conclusion, it should be pointed out that this type of control system could be equally well employed with larger motors for other applications requiring precise speed regulation. While the circuit described is applicable only to a direct current motor, a similar system may be applied to an alternating current motor substituting a saturating reactor in place of the regulating field winding in the manner described by the author in his paper[2] presented before the Society of Motion Picture Engineers, September, 1928.

[2] *S. M. P. E. Transactions*, Vol. 12, No. 35, page 696.