EXPERIMENTAL TRANSMITTING AND RECEIVING EQUIPMENT FOR HIGH-SPEED FACSIMILE TRANSMISSION

V. SYNCHRONIZATION OF TRANSMITTER AND RECEIVER

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The motors which bring about the scanning of the picture areas in the transmitter and in the receiver of the Philips apparatus for high-speed facsimile transmission have to run synchronously with a tolerance of no more than 0.6 degree in their relative phase. This requirement cannot be met with synchronous motors, nor with the system of stabilization by means of tuning-fork generators much used for low-speed facsimile transmission. A new method of synchronization had, therefore, to be developed. A regulating device was employed which reacts to phase deviations between the motors in the transmitter and the receiver, combined with a similar device reacting to differences between the speeds of the two motors. These devices are controlled by synchronizing pulses produced by the optical rotor in the transmitter and transmitted to the receiver together with the facsimile signal, and with the aid of pulses produced by a small generator coupled to the shaft of the receiver motor. Moreover, in the transmitter a device is used which stabilizes the speed of the transmitter motor, so that the synchronization only needs to provide a correction for small variations in the transmitter. With this method it has been possible to reach the necessary phase constancy; in the event of a disturbance the equilibrium is aperiodically restored, with such an inertia that the edge of the recorded picture does not show any disturbing undulation.

Synchronization is a problem of prime importance in all systems of picture transmission, both in facsimile telegraphy and in television. On the transmitting side there is a picture surface traversed by a scanning spot, and at the receiving end a picture surface traversed by a recording spot. Both surfaces are identical and one can imagine them as being divided equally into minute surface elements. To reproduce the transmitted picture in the receiver without any geometrical distortion, the scanning spot and the recording spot must be "synchronized", which means that they must move continuously over corresponding areas of the two picture surfaces at exactly the same moment 1).

1) The transmitted signal has always a finite though very short transit time, T. On closer examination it is seen therefore that the recording spot, the intensity of which is governed by the signal obtained from the scanning spot, must traverse the picture elements with a delay T with respect to the scanning spot. It is not therefore absolutely correct to say that the scanning and recording spots pass over corresponding elements of the two picture areas at exactly the same moment, but this is of no consequence whatever for our further considerations.

The picture surface is always scanned along parallel, adjacent lines. We can therefore express the synchronization condition in a somewhat more concrete form by saying that the scanning spot and the recording spot have to start traversing each line simultaneously and must take the same length of time to cover a line. If the recording spot starts sometimes too early and sometimes too late then the lines in the picture obtained show individual displacements in their own direction; see fig. 1. It is not necessary (and not possible) to exclude such displacements entirely, but the tolerances in this respect are rather small; with a picture width of say 20 cm a maximum line displacement of 1 mm, i.e. 1/200 of the line length, is admissible. Of course such a displacement cannot be allowed between adjacent lines; there must be a gradual transition, so that the edge of the picture shows an undulation with a not too small wavelength. As a normal requirement it is taken that this "wave" must have a wavelength of at least 4 cm (fig. 1).

For the numerous systems of facsimile telegraphy
already existing a number of methods of synchronization have been worked out, none of which however was suitable for our new facsimile system working at a transmission speed about 60 times higher than

the existing systems. Some simple quantitative considerations will make this clear. The method of synchronization devised for this new system will then be described on broad lines.

For the details of the construction of the transmitter and the receiver in the Philips high-speed facsimile system we refer to the four previous articles published in this journal, which will be referred to as I-IV 2).

Synchronous motor and tuning-fork oscillator

Since the synchronization can be reduced to the producing of an identical frequency at the transmitter and receiver, it seems obvious to take advantage of the standard frequency at our disposal in the a.c. mains. In that case the movements of the scanning spot and the recording spot are both brought about by synchronous motors fed from the mains. This method is of course confined to those cases where the mains available for the transmitter and for the receiver are interlinked and therefore always have the same frequency. In such cases this method is indeed successfully applied for low-speed facsimile systems.

Why is this not possible with our system?

In low-speed facsimile transmission the scanning rate is usually about 3 lines per second. The driving two-pole synchronous motors (the most favourable for our purpose) run at the rate of 50 r.p.s. (3000 r.p.m.) in Europe and 60 r.p.s. (3600 r.p.m.) in America, thus making about 20 revolutions in scanning one line. For a permissible displacement of 1/200 line length between transmitter and receiver a phase displacement of $20 \times 360°/200 = 36°$ can be allowed between the motors at the transmitting and receiving ends. The phase displacements between the terminal voltages of the two local mains likely to occur through fluctuations in the instantaneous load will as a rule be well below this limit of 36°. If, therefore, the mutual phase of the scanning elements in transmitter and receiver is properly adjusted at the beginning of the transmission, no prohibitive displacements need be feared.

With our high-speed facsimile system the rate of scanning is 180 lines per second (see article II). A driving synchronous motor would therefore make only $1/3$ revolution in scanning one line. The permissible phase displacement between the motors at the transmitting and receiving ends would thus not be more than $1/3 \times 360°/200 = 0.6°$. One could not possibly reckon on such a phase constancy of the mains.

Consequently synchronous motors cannot be considered for our purpose, not even if it could be expected that interlinked mains would be available at the transmitting and receiving ends.

In very many cases, especially in international communications, this latter condition will certainly not be complied with and for this reason other methods of synchronization have had to be developed already for low-speed facsimile systems. Practically all these methods result in the generation of an oscillation with a frequency of great constancy at the transmitter and receiver, this oscillation being used to control the speed of the motor for the scanning device. The two frequencies are rendered as accurately identical as possible by local adjustment of the frequency-governing element, for instance a tuning fork.

Whereas with the method of synchronous motors the mean speeds are identical and only disturbances due to phase shift fluctuations have to be considered, with these other methods the possible small

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2) Experimental transmitting and receiving equipment for high-speed facsimile transmission:


frequency differences of the local tuning fork oscillator must be considered. The smallest difference in frequency will result in an additional small phase shift of the motors in each cycle. After a large number of cycles this displacement will have accumulated considerably. Suppose that the tuning forks vibrate at such a frequency that \( p \) cycles occur during the scanning of one line. A picture to be transmitted may be 30 cm long, so that given a line width of 0.2 mm the picture may contain in all 1500 lines. Each tuning fork then makes 1500 \( p \) vibrations per picture. If at the end of the picture the line displacement is not to exceed the value of 1/200 line length, the number of vibrations of the tuning fork must not be more than \( p/200 \) out in the 1500 \( p \), that is to say the frequency deviation must not be more than 1 : 300,000.

This requirement can reasonably be met with tuning forks or other vibrating elements if they are very carefully made, but this will not bring us any farther than ensuring that one picture is properly recorded. In order to avoid the consecutive pictures being displaced farther and farther across the picture area, the phase of the scanning device in the receiver has to be corrected after every picture. With the usual low-speed facsimile transmission there is no difficulty in having this correction made for instance by the operators, but in our case, when it takes no more than 8 seconds to transmit a picture of the length mentioned, the operators would have to make this correction every 8 seconds, which of course is out of the question. Or, to put it the other way round, to allow of a correction being made say only once every 10 minutes, a frequency constancy of 1 in \( 2 \times 10^7 \) would be required. Even with the best means available (quartz oscillators in thermostats) this cannot be attained.

There are two possible ways of overcoming these difficulties. According to the first method one is satisfied with a frequency constancy merely sufficient, as described above, for one picture or even less, and an additional mechanism is provided which after every picture or at the required shorter intervals automatically controls the phase of the scanning device in the receiver and where necessary makes a correction to annihilate the phase deviation. By the second method speed is not governed by local tuning devices — which would not possess sufficient frequency constancy anyhow — but the speed of the receiver motor is controlled by a frequency which is derived from the transmitter motor and transmitted together with the picture signal.

The synchronization in our facsimile system may be regarded as a combination of these two methods. It will be seen why neither the first nor the second method alone will suffice.

Stabilizing the speed of the transmitter motor

If one has the means of getting the speed of the receiver motor to follow exactly any speed variations of the transmitter motor then, in principle, it is not essential that the transmitting speed should be kept to a high degree of constancy. However, the smaller the speed variations of the transmitter, the easier it will be, of course, to follow them at the receiver with the necessary accuracy. For this reason, in our facsimile equipment steps have been taken to stabilize the speed of the transmitter motor, and it is well to describe this stabilization first.

The transmitter motor is a direct current motor, the armature of which is fed from a simple (non-stabilized) mains rectifier, whilst the field current is supplied by an output valve of the type EL6. The speed of such a motor is approximately inversely proportional to the magnetic flux in the armature. The motor can therefore be accelerated by reducing the field current and slowed down by increasing the field current. For the normal speed of 60 r.p.s. the current to be supplied by the output valve has to be 55 mA, for which the grid voltage of the valve has to be about —8 V. To stabilize the speed it is arranged that the grid potential of the output valve becomes more positive as the motor begins to rotate at a higher speed. The resulting increase of the anode current flowing through the field winding then counteracts the increase in speed.

This regulating voltage at the grid of the output valve is derived in the following way. On the shaft of the motor a small generator is fitted which at a speed of 60 r.p.s. produces an alternating voltage with a frequency of (for instance) 180 c/s. This alternating voltage is applied to an L-C circuit tuned to a frequency slightly higher than 180 c/s, such that the resonance curve has its steepest slope at 180 c/s; see fig. 2. Consequently the amplitude of the voltage across the circuit will vary considerably when the frequency of the alternating voltage supplied, that is to say the speed of the motor, changes but slightly. The voltage across the circuit is now rectified, and the direct voltage obtained — from which is to be subtracted a constant bias determining the working point — serves as control grid voltage of the output valve. A block diagram of this stabilizing circuit is given in fig. 3.

Let us now consider the working of this stabilization more closely. In the event of an interference,
for instance a slight variation in the armature voltage or in the load of the motor, which has the tendency to change the speed, the field current changes to such an extent as to compensate the effect of the interference very rapidly. This means

\[ 180, 200 \text{ per sec} \]

Fig. 2. Resonance curve of the tuned circuit employed for stabilizing the speed of the transmitter motor.

that the equilibrium corresponding, say, to a changed armature voltage, is already obtained with an extremely small change in speed. An actual and permanent small change in the speed, however, is indispensable. The effect of the stabilization therefore is only that the speed change required for the new equilibrium is considerably reduced as compared with the case where there is no stabilization.

In our installation the reduction factor has been made very large by keeping the damping of the L-C circuit low, namely by limiting the damping effect of the coupled rectifier with the aid of a special circuit (cf. fig. 6). In this way a resonance curve is obtained with steep sides, and the anode current of the output valve (i.e. the field current of the motor) will therefore greatly vary with the speed, due also in part to the high mutual conductance of this valve. In our case, for an interference due to variation of the armature voltage, the reduction factor is 270. For a variation of the load it is still higher.

![Fig. 3. Circuit diagram for stabilization of the speed of the transmitter motor.](image)

Regulating the speed of the receiver motor

In the first place the receiver is equipped with a speed-stabilizing device very much resembling that in the transmitter. The motor is of the same type; the field current is supplied by an output valve; the latter is controlled by the rectified voltage of a tuned circuit which in turn is excited by an alternating voltage of 180 c/s obtained from a small generator on the motor shaft. Here again negative grid bias is added to the regulating voltage for correctly adjusting the working point of the valve.

The result of this stabilization is that the effect of mains voltage fluctuations, etc., on the speed of the receiver motor is very greatly reduced, as is the case with the transmitter. At the same time, however, it affords a very simple means of satisfying the desire for the speed of the receiver to be continuously controlled by that of the transmitter. For this purpose an alternating voltage of a frequency proportional to the speed of the transmitter motor is transmitted by cable from the transmitter to the receiver. There this voltage is applied to a tuned circuit corresponding to that in the transmitter, and the rectified voltage of this circuit is used for stabilizing the receiver motor, instead of the constant grid bias of the output valve. At the end of the previous section we have already pointed out that with the regulating method

\[ 3) \] One might use for this the already mentioned voltage of the generator on the shaft of the transmitting motor. Actually we use the "synchronization signals" referred to already in articles II and IV. This point is considered further in what follows.
described the nominal speed can be adjusted by choosing a suitable value for this grid bias. Now in this manner a variation in the speed of the transmitter will cause also a variation of the nominal speed at which the stabilization of the receiver is working. A block diagram of this method of synchronization is shown in fig. 4.

Regulating the phase of the receiver motor

As already stated, the receiver motor drives a small generator supplying the alternating voltage required for stabilizing the speed. This generator consists of a fixed magnet with an inductor and a rotating armature with three teeth. The teeth are so shaped as that one of them passes the magnet a voltage pulse is generated in the inductor. When the motor is running at the nominal speed of 60 r.p.s. there are thus 180 pulses per second. The fundamental frequency of 180 c/s filtered out of these pulses is used for the speed-stabilizing system (fig. 4). The impulses themselves are required for the phase control now to be described.

The synchronizing alternating voltage of the transmitter, mentioned above, also consists of pulses. These are obtained by optical means, i.e., by the three rotating, optical scanning systems in the transmitter (see article II); alongside the edge of the document to be scanned is a somewhat specular aluminium plate; an pulse of constant height and duration is thus introduced in the facsimile signal at the beginning of each scanning line. These pulses, which serve not only for the synchronization but also for reconstructing the scale of blackness of the picture (see article IV), are transmitted along the cable together with the signal; thus no separate channel is needed for the synchronization signals.

To achieve the speed regulation in the receiver already described (fig. 4) the fundamental frequency of 180 c/s is again filtered out of the transmitted pulses and used. For the phase regulation, however, the transmitter pulses are converted by means of a simple network into a saw-tooth voltage, and to this are added the pulses of the receiver generator. When the two motors are running at the same speed a purely periodical voltage is obtained in the form as represented in fig. 5.

The position of the pulse on the "back" of the saw-tooth is apparently directly related to the mutual phase of the transmitter and the receiver. By suitably positioning the inductor in relation to the armature on the shaft of the receiver motor it
can be arranged that for the desired phase relation (the recorded line in the receiver beginning at the edge of the picture plane) the pulse just comes to lie midway between the fly-back surges of the saw-teeth.

![Saw-tooth and periodical pulse added together.](image)

If the cause of a phase displacement persists then it is not possible for the phase to be fully restored, just as we have seen with the methods of regulation first described. The effect of an interference is only reduced, that is to say the new equilibrium is already obtained at a very small displacement of phase. It is found possible to make the reduction factor sufficiently large to satisfy our demands as regards the phase constancy (maximum phase shift 0.6°). This is achieved, apart from other means, by making the saw-tooth steep; thus the amplitude of the saw-tooth voltage high (about 250 V), so that even small phase displacements result in a considerable change in the amplitude of the pulses.

For the control to act at any mutual phase position of transmitter and receiver, the amplitude of the pulse must, wherever it lies, exceed that of the saw-tooth; the amplitude of the pulse must therefore be made at least equal to that of the saw-tooth. The amplitude of the pulse and

![Diagram of the phase regulation. Again an output valve is used (E') to supply a part of the current for the field winding B' of the receiver motor. This valve is controlled by the output voltage of the rectifier Gs', this being proportional to the difference between the peak value and the mean voltage of the A.C. input voltage. The input voltage for the rectifier is the voltage illustrated in fig. 5, part of this voltage is supplied by the receiver (O) and part of it by the transmitter (Z). The variable bias H ensures that the voltage υg in the right phase position assumes the value of −3 V corresponding to the desired working point of the output valve.](image)

This voltage according to fig. 5 is conducted to a rectifying circuit which supplies a voltage equal to the difference between the peak of the pulse and the mean value. This direct voltage is applied, in series with an adjustable bias, to the grid of an output valve and anode current of which forms part of the field current for the receiver motor; see fig. 6.

In the event of the receiving motor lagging in phase behind the transmitting motor for some reason or other, the pulses come to lie farther to the right on the saw-tooth. Thus, its top lies lower, the output voltage of the rectifier is smaller, and when the polarity is suitably chosen the grid voltage of the output valve becomes more negative and as a consequence the field current of the motor is reduced. The result is that the motor is accelerated, so that it begins to make up for the phase lag in relation to the transmitter motor. In this way the original phase relation between transmitter and receiver is restored.

The equilibrium is also determined in part by the grid bias of the regulating valve. By varying this bias the phase relation between transmitter and receiver can be adjusted at the beginning of a transmission. For this purpose the potentiometer with which the grid bias is varied is provided with a control knob on the front panel. Also mounted on the front panel is a meter indicating the phase difference, whilst furthermore the form of the voltage illustrated in fig. 5 can be checked with the aid of a small cathode-ray oscilloscope. These devices are shown in the photograph reproduced in fig. 7.
that of the saw-tooth voltage must be kept accurately constant, because any variation would just as well cause the voltage across the rectifier to change as a phase displacement. Consequently the incoming pulses of the transmitter and the receiver are not applied directly but first limited to a constant level in the usual way.

Phase control can only be effective when the speeds of the transmitter and receiver are already practically equal. If there is any appreciable difference in the speeds then the pulse runs very rapidly over the back of the saw-tooth right to the end and then begins again at the other end. The rectified voltage would therefore have to rise and decay at the same rate. Owing to the necessary smoothing of the output voltage of the rectifier, however, the speed difference is neutralized and its cause can only bring about a displacement of the equilibrium to a somewhat different phase relation, as we have already seen above 4).

It may now be asked why, then, this phase control alone does not suffice.

Phase control can only be effective when the speeds

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4) In the terminology of control technique the phase control might be termed an "integral control" of the speed. Integral controls have the property of being able to make the mean value of the quantity to be adjusted exactly equal to a prescribed value.
grid voltage of the output valve corresponds to the average peak height, and consequently the total effect of the rapid phase variations upon the speed of the motor is nil. (As a matter of fact this would also be the case without smoothing, because the inertia of the armature would render rapid variations of the torque ineffective.)

The incapability of the phase control to correct large speed deviations is particularly manifest in the fact that when the receiver motor is started it will as a rule not be brought up to the desired speed. This is actually done by the speed control. After being switched on the receiver motor starts running and tries to reach the rated speed to which the speed stabilization is set. The speed regulation by means of the synchronization signals corrects this in so far that it brings the speed of the receiver anyhow very close to the speed of the transmitter. This means that the pulse in fig. 5 runs more and more slowly over the saw-tooth until the phase control comes into operation and keeps the pulse in a certain position. The phase relation can then be further adjusted by hand, as explained above.

Though easy starting is in itself sufficient justification to apply speed control in addition to phase control, there is a second reason for this which we regard as being still more important. In order to explain this reason we must first look at one side of the problem that has so far been neglected, namely the behaviour of this regulation as a function of time. In the description given above we have spoken only of the state of equilibrium, but how is a new equilibrium attained after an interference has taken place?

If the angle of rotation of the transmitting motor with respect to an arbitrary initial position is \( \phi \), then in the event of an interference the angle of rotation of the receiver motor with respect to the corresponding initial position will not be exactly equal to \( \phi \), but \( \varphi = \phi + \psi \). Thus \( \psi \) is the undesired phase deviation. Now there are a number of torques acting upon the shaft of the receiver motor. The normal field present when there is no disturbance in the running of the motor supplies a driving torque \( M_d \). Friction sets up a braking torque, which for our purpose we can express to a sufficient approximation by \( M_f = a + b \phi \), in which \( a \) and \( b \) are constants. The phase control yields a correcting torque \( M_c \), which is opposed to the phase displacement \( \psi \) and which for small deviations we can take as being proportional to \( \psi \): \( M_c = c \psi \). Similarly the speed control yields a correcting torque \( M_d \) proportional to the speed difference \( \dot{\psi} - \dot{\phi} \), thus \( M_d = d \dot{\psi} \).

Using \( I \) to denote the moment of inertia of the armature and the rotor of the scanning device coupled to it, for the rotation of the receiver motor we have the differential equation:

\[
I \ddot{\psi} - M_0 + (a + b \phi) + M_c + M_d = 0.
\]

Substituting \( \varphi + \phi + \psi \) and putting \( \dot{\phi} = 0 \), since we shall assume the transmitter motor to rotate at a constant speed, we then have

\[
I \ddot{\psi} - M_0 + a + b \dot{\phi} + b \psi + M_c + M_d = 0.
\]

This equation must also hold for the undisturbed state where \( \psi = 0 \). Hence \( M_0 = a + b \dot{\phi} \), so that our equation becomes

\[
I \ddot{\psi} + b \dot{\psi} + M_c + M_d = 0. \quad \ldots \quad (1)
\]

Let us now first consider the effect of the phase control alone. For the time being we therefore take the term \( M_d \) as being zero. Substituting \( M_c = cv \), we then see that eq. (1) assumes the form of the well-known equation for a damped oscillatory vibration without an external force acting upon the vibrating system. From this we can at once conclude that when an arbitrary deviation \( \psi \) is introduced and the system is further left to itself the relative phase ultimately returns to its original value \( \psi = 0 \). The relation of the damping term (coefficient \( b \)) to the other terms will determine whether this return of the relative phase to its original value takes place in an oscillatory manner or aperiodically.

This, however, is still incomplete. We have to take into account the fact that both in the phase control and in the speed control there is a delay time \( \tau \) respectively \( \tau_1 \). This is for a large part attributable to the RC-constant of the rectifying circuits supplying the grid voltage for the regulating valves and that of the smoothing filters, and also for a part to transients, for instance in the tuned circuits, and to the hysteresis of the iron circuit of the motor. The delay means that the correcting torques \( M_c \) and \( M_d \) at the instant \( t \) are determined by the phase and speed deviations respectively which were present at a time \( \tau \) respectively \( \tau_1 \) earlier. Thus:

\[
M_c (t) = c \psi (t - \tau); \quad M_d (t) = d \dot{\psi} (t - \tau_1).
\]

If we now develop both these expressions in progressions according to Taylor we get:

\[
M_c (t) = c [\psi (t) - \tau \dot{\psi} (t) + \frac{1}{2} \tau^2 \ddot{\psi} (t) \ldots], \quad M_d (t) = d [\dot{\psi} (t) - \tau_1 \ddot{\psi} (t) \ldots].
\]

For these qualitative considerations we may ignore higher terms of the series. By substituting these expressions we derive from eq. (1):
As is to be seen, the coefficients of the equation for the vibration are altered owing to the retardation effects. In particular it is to be noted that now the damping term may also become negative \((b, c\) and \(d\) according to their definition are positive), namely when \(c\) is too large. The phase deviation \(\psi\) will then fluctuate around the zero value; but the fluctuations will become larger and larger. This phenomenon may indeed occur in practice and would, of course, render the control useless. This is all the more unwelcome because a high value of the coefficient \(c\), indicating the “amplification” of the phase regulation, is desired for a large reduction factor in this regulation.

This now, is where advantage is again taken of the speed regulation. The contribution of this regulation towards the damping term consists in the positive quantity \(d\) appearing in eq. (2). By making \(d\) large, we can therefore always make the damping positive, even when \(c\) has a very large value. In particular, regardless of the choice of \(c\), we can now give the damping such a value as to render the system aperiodic, this being the most favourable condition for our purpose. In order to facilitate this we have kept the delay time \(\tau\) as small as possible, inter alia by arranging the aforementioned rectifying circuits in such a way that they can have a short RC-time without causing any excessive ripple in the direct voltage supply (cf. fig. 6). As may be seen from eq. (2), the delay time \(\tau_1\) of the speed control has no effect upon the damping.

A high value of \(\tau_1\), as also of \(d_1\), however has an adverse effect upon the inertia term. Its effect is adverse because the aperiodic response of the system should be such that the final value is reached at a sufficiently slow rate. At the beginning of this article it has been stated that the edge of the picture may take the shape of a wave with a minimum wavelength of \(4\) cm. This means that a phase displacement of the maximum value may be made to disappear (or brought to the new final value) only after \(2\) cm picture length, that is to say after about \(\frac{1}{2}\) second. The inertia term in eq. (2) must be made sufficiently large to bring this about.

It was found, however, that this requirement could be easily met, independently of the reduction factors and delay times of the two controls, by increasing the moment of inertia \(I\) with the aid of a flywheel on the motor shaft.

Finally we give in fig. 8 a simplified diagram of the whole synchronization system, showing how the phase control and the speed control have been combined. Each of the controls works on a separate output valve yielding a contribution to the field current of the receiving motor \(^6\). A resistor \((R_a)\) shunted across the output valves ensures that there is a certain field even when the valves are cut off, thus allowing for automatic starting (without the armature current reaching an excessive value); this also ensures that in the event of failure of the control voltages the motor will not race. The adjustment of the desired aperiodic damping of the phase variations is brought about not by the choice of the coefficient \(d\), that is the amplification of the speed regulation, but by the choice of \(c\), the amplification of the phase control, with the aid of the potentiometer \(P\). The motive for this lies in the fact that the reserve in the sensitivity of the phase control in the synchronization circuit proved to be much greater than that in the speed control.

\(^6\) Actually the two controls are “mixed”, for although two regulating valves are used we apply to the grid of each valve a voltage composed of fractions of the two regulating voltages.