general very greatly influenced by the potential of the insulator which will change about equally with the anode voltage. The secondary electron current which reaches the anode will therefore also change sharply with the anode voltage, and this means that the internal resistance becomes considerably lower and the amplification of the high-frequency stage diminishes.

In order to avoid these harmful effects here again several methods may be chosen. When, for example, the disturbing phenomenon is due to insulating supports within the system, the most practical solution will be to cover them with a substance whose secondary emission is less than unity (for instance a layer of carbon). If the danger spot is the inner side of the bulb, the jump in potential can also be avoided by earthing this surface through a capacity. In order to do this the outside of the bulb may be covered with a layer of metal which is kept at a low potential (that of the cathode for instance). Finally the charging of the wall of the bulb may be avoided by entirely preventing electrons from leaving the electrode system and reaching the glass wall. This may be achieved by means of shields. Fig. 12a shows a power amplifier valve with a massive anode whose ends are closed by caps which make it impossible for electrons to leave the anode. If an anode in the form of a gauze is used as is often necessary in order to improve the heat radiation of the components within the anode, this shielding must also be extended behind the anode. For this purpose a wire gauze cage at cathode potential is suitable. Electrons are unable to pass through this cage to the outside (fig. 12b). Shields with a low potential may also be introduced in front of the much used mica supports at the extremities of the system in order to prevent their being struck by electrons.

AN APPARATUS FOR THE MEASUREMENT OF SCANNING SPEEDS OF CATHODE RAY TUBES

by L. BLOK.

A simple apparatus is described for the determination of the greatest scanning speed of cathode ray tubes which can be photographed. The light spot on the screen is allowed to describe a logarithmic spiral, at every point of which the speed can easily be determined. The point of least intensity on the spiral which is still sufficiently visible in the photograph determines the maximum scanning speed required.

If, with the help of a cathode ray tube, phenomena are investigated which are not periodic or stationary, but only occur once, it will in general be found practical to record the phenomenon photographically. In the most commonly occurring cases the details cannot be adequately studied by visual observation.

As examples of phenomena which are investigated in this way we may mention the switching on of transformers, break-down in the testing of insulating materials, back-surge in rectifiers, atmospheric discharges, etc.

In the photographic recording of such a phenomenon the blackening of the light-sensitive plate will depend on:

a) the brightness $B$ of the cathode ray light spot,
b) the diameter of the spot $D$,
c) the velocity $v$ at which the spot moves,
d) the optical enlargement $N$, 
e) the light sensitivity $\eta$ of the photographic material.

A detailed treatment of the relation between blackening and the factors a) to e) has already been published in this periodical 1), together with a discussion of measurements relating to the maximum scanning speed. As a control in the manufacture of cathode ray tubes it is desirable to be able to determine this scanning speed in a simple way. In the following a description is given of a measuring apparatus solved for this purpose.

Principle

In order to determine the scanning speed by means of a single photograph it is necessary to allow the spot to describe a path on which the velocity changes continuously, while at every point of the path the velocity must be known with sufficient accuracy. One may then determine on the photograph the point where the path of the spot

is still just sufficiently visible. The velocity at that point is then the maximum scanning speed which can be photographed under the given conditions.

A very simple solution of the problem is obtained when the light spot describes a logarithmic spiral with a constant angular velocity.

This curve may be represented in polar coordinates by the following equation:

\[ \rho = A e^{-a\varphi} \quad \ldots \ldots \quad (1) \]

The exponent of \( e \) is taken negative so that with increasing argument \( \varphi \) the radius vector \( \rho \) decreases (fig. 1). If \( \varphi \) is made linearly dependent on the time by setting

\[ \varphi = \omega t \quad \ldots \ldots \quad (2) \]

where \( \omega \) is a suitable angular velocity we obtain:

\[ \rho = A e^{-a\omega t} \quad \ldots \ldots \quad (3) \]

when \( t = 0, \rho = A \), when \( t = \infty, \rho = 0 \).

The velocity at any point \( P \) of the spiral (v. fig. 1) is given by:

\[ v = \sqrt{v_1^2 + v_2^2} \]

where \( v_1 \) is the radial velocity and \( v_2 \) the velocity perpendicular to the radius vector. We now have the relation:

\[ v_1 = \frac{d\rho}{dt} \quad \text{and} \quad v_2 = \frac{d\varphi}{dt} = \rho \omega \]

From equation (3) we find that:

\[ v_1 = \frac{d\rho}{dt} = -a \omega A e^{-a\omega t} = -a \omega \rho \]

so that:

\[ v = \sqrt{a^2 \omega^2 \rho^2 + \rho^2 \omega^2} = \rho \omega \sqrt{a^2 + 1} \quad \ldots \ldots \quad (4) \]

If \( a^2 \) is made small with respect to unity, the radial velocity \( v_1 \) becomes small with respect to the velocity \( v_2 \), and the distance between successive coils of the spiral becomes small with respect to the radius \( \rho \). Then for the velocity \( v \) we obtain by approximation:

\[ v = \rho \omega \quad \ldots \ldots \quad (5) \]

This expression gives the velocity of a point which describes a circle with an angular velocity \( \omega \) and a radius \( \rho \). The approximation employed therefore comes down to this, that the number of windings of the spiral must be so great that an element of the curve may be considered as an element of a circle.

Application of principle

In order to find out how a spiral can be obtained on a cathode ray tube by an electrical method, we pass over to rectangular coordinates.

For this purpose we take:

\[ x = \rho \cos \varphi = Ae^{-a\varphi} \cos \varphi \]
\[ y = \rho \sin \varphi = Ae^{-a\varphi} \sin \varphi \]

With \( \varphi = \omega t \) this becomes:

\[ x = \rho \cos (\omega t + \frac{\pi}{2}) \]
\[ y = \rho \sin (\omega t) \]

where \( \omega \rho \) is set equal to \( b \).

\( x \) and \( y \) as functions of the time \( t \) have the form of two damped oscillations which differ in phase by 90°. Since the deflection of the spot on the screen is proportional to the potential difference between the plates, it is sufficient to apply a damped sinusoidal oscillation to each set of plates differing in phase by 90°.

Such a voltage is obtained in a simple manner by giving an LCR circuit an electrical impulse, and allowing it to die out in oscillations of its own frequency according to the well-known equation:

\[ V_t = V_0 e^{-\frac{R_t}{2L} \cos \omega t} \]

where \( V_0 \) is the voltage on the circuit due to the impulse at the moment \( t = 0 \). \( V_t \) the voltage at the time \( t \), \( R \) the series resistance, \( L \) the self-inductance of the circuit, \( R/2L \) the damping factor and \( \omega = 2\pi f \), in which \( f \) is the frequency of the circuit itself.

By applying this voltage to the primary winding \( P \) of a transformer which has two separate equal secondary windings \( S_1 \) and \( S_2 \) (fig. 2), two similar secondary voltages are obtained of the same form as the primary voltage.
In order to obtain the desired phase difference, \( S_1 \) is loaded with the resistance \( R_1 \) and the condensers \( C_1 \) and \( C_2 \), and \( S_2 \) with \( R_2 \), \( R_3 \) and \( C_3 \), which are chosen so large that:

\[
\frac{1}{\omega C_1} + \frac{1}{\omega C_2} = R_1 \quad \text{and} \quad R_2 + R_3 = \frac{1}{\omega C_3}.
\]

while in addition it is provided that:

\[
R_1 = 2R_2 = 2R_3 \quad \text{and} \quad C_1 = C_2 = 2C_3.
\]

In this way the voltage \( V_{R_1} \) on \( R_1 \) is made equal to the voltage \( V_{C_3} \) on \( C_3 \), while both are symmetrical with respect to earth and, moreover, the phase difference between \( V_{R_1} \) and \( V_{C_3} \) is exactly 90°.

With a cathode ray tube the proportionality factor between voltage and deflection is not the same for both pairs of deflection plates. The spiral obtained will therefore be "oval". By applying the voltage \( V_{R_1} \) which can be regulated with the potentiometer \( R_0 \) to the more sensitive plates, this difference may be compensated and the spiral becomes "circular".

**Description of the circuit**

The diagram of the circuit may be seen in fig. 3. The positive pole of the high voltage apparatus which supplies the anode voltage is earthed. When the switch \( S_1 \) is in position 1, with the help of potentiometer \( R_4 \) the voltage of the grid \( g \) of the cathode ray tube can be regulated, and thereby the strength of the electron current. When \( S_1 \) is in position 2, \( g \) becomes about 200 volts more negative than the cathode \( k \) and the current of electrons is thereby suppressed.

With switch \( S_2 \) in position 1, on changing \( S_1 \) from 2 to 1, the adjusted electron current begins to flow and a voltage impulse occurs on the grid of valve \( L_1 \). The oscillating circuit \( LRC \) thereby receives an impulse so that on the primary winding of the transformer in the anode circuit of \( L_2 \) the desired damped sinusoidal oscillation occurs. There is a potential of more than 2000 volts on condenser \( C_0 \) which must be constructed accordingly.

For good adjustment of the camera it is desirable that it be focussed upon the spiral itself. For this purpose it is also necessary to be able to obtain a permanent image of the spiral on the screen of the cathode ray tube. To do this, a sawtooth voltage generator \( e(t) \) is connected over the condenser \( C' \) by means of switch \( S_2 \) in position 2. When \( R' \) and \( C' \) are correctly chosen, this sawtooth voltage \( e(t) \) gives periodic impulses to \( L_1 \) with a frequency depending on the frequency of the sawtooth voltage. For the circuit in which this voltage works the following holds:

\[ e(t) = VC' + VR'. \]

in which \( VC' \) is the voltage on the condenser \( C' \) and \( VR' \) that on \( R' \).

Upon substituting \( VC' = \int \frac{i}{C'} \, dt \) where \( i \) is the
prevailing current and \( i = V_{R'}/R' \), we may write:

\[
e(t) = \int \frac{V_{R'}}{R'C'} \, dt + V_{R'}, \quad \text{or, differentiating,}
\]

\[
\frac{d}{dt} e(t) = \frac{V_{R'}}{R'C'} + \frac{d}{dt} V_{R'}.
\]

If \( C'R' \) is sufficiently small, the first term of the right hand member of the equation dominates, and we may safely write the voltage derivation in approximation:

\[
\frac{d}{dt} e(t) \approx \frac{V_{R'}}{R'C'}
\]

The voltage on \( K' \) and therefore supplied to the grid of \( L_t \) is proportional to the derivative of the voltage \( e(t) \) with respect to time.

\[\begin{align*}
\text{Fig. 4, Form of the sawtooth voltage } e(t) \text{ and of its derivation } \frac{d}{dt} e(t) \text{ as a function of the time.}
\end{align*}\]

The form of the voltage \( e(t) \) as a function of the time is indicated in fig. 4a, while in fig. 4b the variation of \( V_{R'} \) as a function of \( t \) is drawn for sufficiently small values of \( C'R' \). The latter figure shows plainly the occurrence of periodic impulses. Each of these impulses causes the spiral to be described once. In this way a permanent image appears on the screen of the tube. If the time between two impulses is made shorter than that necessary for the almost complete fading of the oscillations of the circuit, the light spot can no longer reach its point of rest. It then does not form a point in the center, but ends at an arbitrary point on one of the windings. An interesting effect is obtained when the frequency of the impulses is continuously increased. The spiral is then seen to be erased from the center outwards.

In recording a spiral the method is as follows. \( S_1 \) is set in position 1, \( S_2 \) in position 2 and the camera is focussed on the spiral on the screen. After the lens has been closed the plate or film is introduced. \( S_1 \) is then set on 2 and \( S_2 \) on 1, the shutter is opened and \( S_1 \) switched back to 1, which causes the

\[\begin{align*}
\text{Fig. 5, Photograph for the determination of the scanning speed of a cathode ray tube DG 16. Electron current 50 \mu A, anode voltage 2000 volts, ratio of size of photograph to object 1 : 1, aperture of lens 1 : 6.3, Agfa Isochrom plate.}
\end{align*}\]