

Jan. 17, 1956

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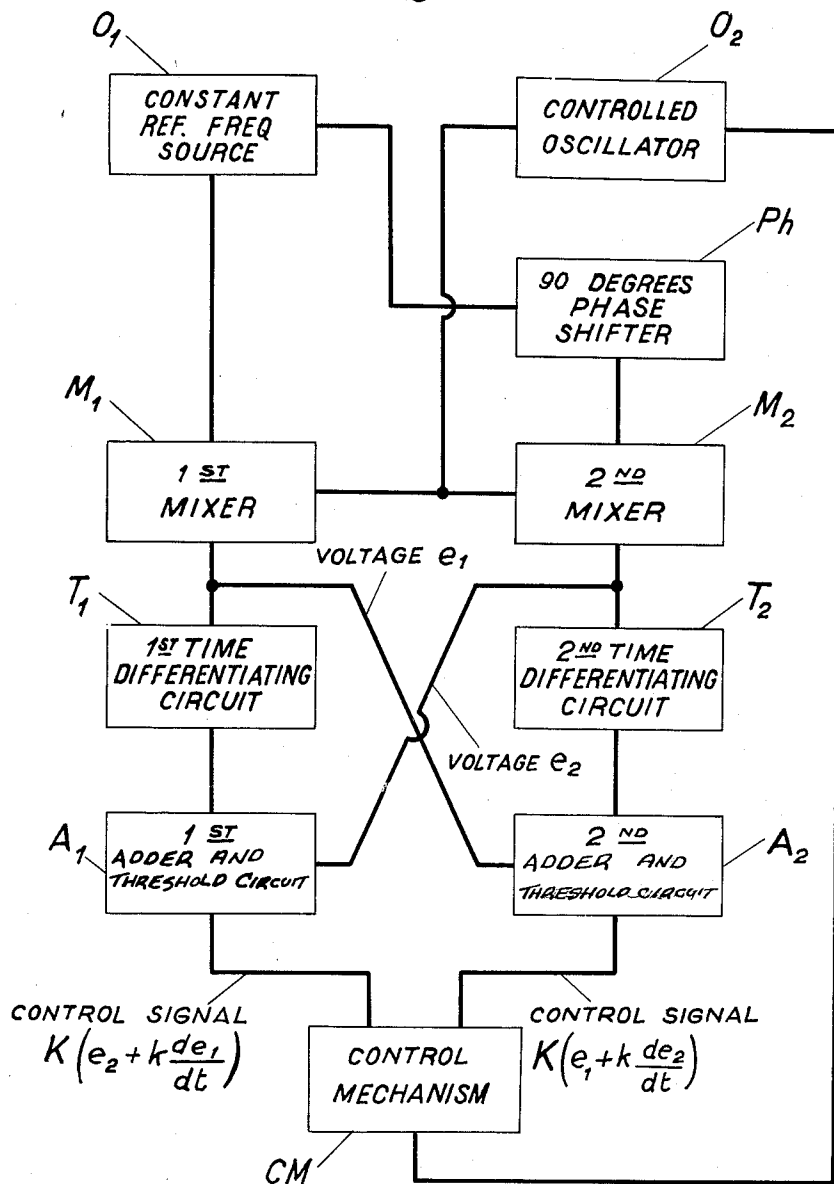
2,731,566

FREQUENCY STABILIZING DEVICE

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2 Sheets-Sheet 1

Fig. 1



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Fig. 2

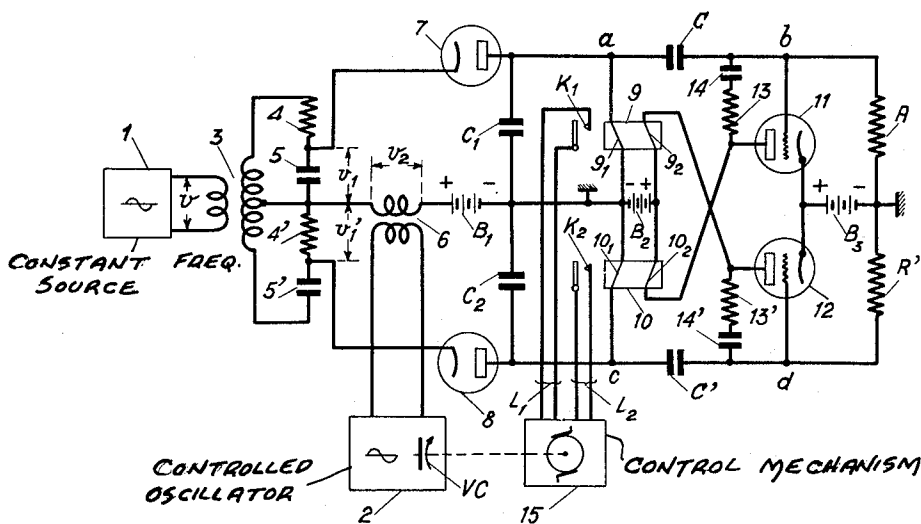
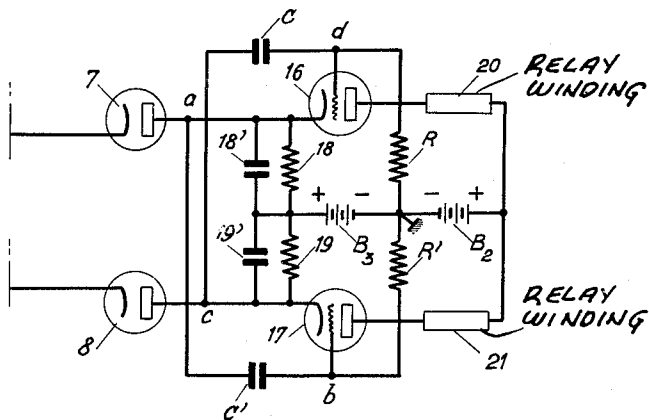


Fig. 3



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FREQUENCY STABILIZING DEVICE

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Claims priority, application France April 11, 1947

3 Claims. (Cl. 250—36)

This application is a continuation-in-part of my application, Serial No. 18,618, filed April 2, 1948, for "Sinusoidal Frequency Regulating System" now abandoned.

The present invention relates to a device which makes it possible to stabilize the frequency of a controllable oscillator by means of that of a constant reference frequency oscillator and to correct the first or controllable oscillator whenever the frequency thereof differs by more than a predetermined, finite amount by excess or defect from the said reference frequency.

Various systems for the same purpose are already known, such as those described in U. S. Patents to Clarence W. Hansell No. 2,104,801 for "Frequency Control" and to G. L. Usselman No. 2,387,544 for "Frequency and Phase Comparison, Detection and Control System." Both systems described in the said patents are based on the fact that if beats are produced between two voltages, the frequencies of which are to be compared, a first time in any manner and the second time in the same manner but after shifting the phase of one of the two said voltages by an angle close to 90°, the two beats thus obtained are themselves shifted in phase by about 90° but the order of occurrence in time of their respective maximum amplitudes depends on the sign of the difference between the compared frequencies; that is to say if the frequency of the controllable oscillator is the higher, one of the said beats will "lead" the other one by one fourth of a period of the beat frequency (which is equal to the difference of the compared frequencies) while, in the opposite event, the conditions will be reversed.

In the above-cited Hansell patent, the beat voltage maximum occurring first is used for locking, for a certain time, an amplification path for the other beat voltage and a device is described which supplies two currents, one or the other of which is the larger according to whether the control frequency is higher or lower than the reference frequency, said currents being used for controlling the controllable oscillator.

In the system described in the above mentioned G. L. Usselman patent, two beat voltages mutually shifted in phase by 90° are produced and the time relationship existing between the instants of occurrence of their respective maximum amplitudes is used to control a tripping device causing one or the other of two control signals to be emitted according to the position of the said tripping device, which is a function of the said time relationship, and, consequently, of the sign of the frequency difference to be corrected.

Murray G. Crosby, in U. S. Patent No. 2,377,326, for "Automatic Frequency Control System," describes a method in which only one beat voltage is involved, this beat voltage being frequency modulated, during a beat cycle, by an appreciable amount if the mixed voltages have amplitudes fairly close to each other in value. The amplitude modulation and the frequency modulation of the resulting beat voltage offer different relative phases

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according to the sign of the difference between the compared frequencies and it is this phenomenon which enables Crosby to achieve the desired result by means of a discriminator and a demodulator.

The device which is an object of the present invention differs from the above cited patents by the use of different means for obtaining the desired result. In the device according to the present invention, as in other previously known devices:

1. A correction signal is generated which indicates without any ambiguity whether the frequency of the controlled oscillator is higher or lower than the reference frequency, said signal making it possible to correct the controlled oscillator in a suitable direction.

2. No signal is generated when the frequency of the controlled oscillator is sufficiently close to the reference frequency to make it unnecessary and even undesirable to effect a correction on the controlled oscillator.

However, according to the method of the present invention, these results are obtained by comparatively simple means, hereinafter described.

The constant reference frequency source already referred to may be, in practice, a well-stabilized oscillator or a distant source, for instance a pilot signal received from some distant point, and suitably amplified. Nevertheless, for simplicity of language, the said means will hereafter be referred to as the "reference oscillator" whatever its material nature may be.

The basic operating principle of the device of the invention may be explained as follows:

Designating by Ω the common frequency of the two beat voltages e_1 and e_2 , received, for instance, at the outputs of two mixers, Ω being taken as a positive or negative quantity according to the sign of the difference between the compared frequencies, the said beat voltages may be respectively represented by such expressions as:

$$e_1 = E \cos (\Omega t - \phi)$$

and

$$e_2 = E \cos \left(\Omega t + \frac{\pi}{2} - \phi \right)$$

E being a constant and ϕ a constant phase angle.

By combining each of the said voltages e_1 and e_2 with the derivative with respect to time of the other one, new signals S_1 and S_2 can be obtained represented by such expressions as:

$$S_1 = K \left(e_1 + k \frac{de_2}{dt} \right)$$

and

$$S_2 = K \left(e_2 + k \frac{de_1}{dt} \right)$$

K and k being constant quantities.

Substituting the suitable expressions for the derivatives in the brackets it is found that:

$$S_1 = K E (1 - k \Omega) \cos (\Omega t - \phi)$$

$$S_2 = K E (1 - K \Omega) \cos \left(\Omega t - \phi + \frac{\pi}{2} \right)$$

The latter expressions immediately show that the amplitudes of S_1 and S_2 are different, either of them being alternately the larger or the smaller one according to the sign of the frequency difference Ω .

It must be noted that the above mentioned differentiation of e_1 and e_2 with respect to time is not equivalent to a simple 90° phase shifting, as it introduces Ω as a multiplying factor in the amplitude difference between S_1 and S_2 , a highly advantageous feature of the invention.

According to the present invention, there is provided

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a device for stabilizing the frequency of an oscillator delivering a controllable frequency voltage comprising, in combination, a constant reference frequency voltage source, a first mixer circuit fed from both of said reference and controllable frequency voltages and producing a first beat voltage, means including at least one phase shifter for relatively shifting by substantially 90° the phases of said reference and controllable frequency voltages, a second mixer circuit fed from said relatively phase shifted voltages and producing a phase shifted second beat voltage, a first and a second time differentiating circuits respectively fed from said first and second beat voltages and delivering a first and a second derived voltages respectively proportional to the time derivatives of said first and second beat voltages, a first and a second adder circuits each fed from one of said beat voltages and from the derived voltage proportional to the time derivative of the other of said beat voltages and modified by its passing through a biased electron tube, each of said adder circuits supplying a control signal proportional to the sum of the said beat and modified derived voltages applied thereto, means for actuating a control mechanism by said control signals through a pair of electromagnetic relays and means for controlling the frequency of said controllable frequency oscillator by said control mechanism.

The operation of the device which is the object of the present invention will be better understood by reference to the appended drawings, wherein:

Figure 1 is a block diagram the purpose of which is to facilitate the understanding of the operation of the device of the invention;

Figure 2 is a diagram showing a particular embodiment of the invention; and

Figure 3 is a diagram showing another embodiment of the invention.

Figure 1 shows, in block diagram, the various parts of the device of the invention as just defined, namely the constant reference frequency source O₁, the controllable oscillator O₂, a phase shifter Ph, the first and second mixers M₁ and M₂, the first and second threshold and adder circuits A₁ and A₂, the control mechanism CM and the suitable connections between the said elements.

In the diagram of Figure 2, an oscillator 1 delivers a voltage v , the frequency of which, ω_1 , is chosen as the reference frequency; the oscillator 2, which shall be called, hereinafter, the controlled oscillator, delivers a voltage v_2 at the frequency ω_2 , which it is desired to keep very close to ω_1 . The control of the frequency of the latter oscillator may be materially effected by one of the usual means, for instance by means of a variable capacitor VC actuated by a motor 15 which can rotate in one or the other direction according to whether contact K₁ or K₂ is closed on line L₁ or L₂.

As in the above mentioned patents, there are derived, from voltage v , which is fed to the primary winding or transformer 3, substantially equal magnitude voltages v_1 and v_1' , mutually shifted in phase by about 90°, said voltages v_1 and v_1' being respectively found across capacitor 5 and resistance 4' in the series capacitor resistor arrangement 4, 5, 4', 5' connected across the secondary winding of transformer 3. This can always be achieved by suitable dimensioning of 4, 4' and 5, 5'; voltage v_2 from oscillator 2 is, on another hand, obtained through transformer 6.

Thus, the following voltages are available between the points indicated on Figure 2.

$$v_1 = V_1 \sin \omega_1 t$$

$$v_1' = V_1 \sin \left(\omega_1 t + \frac{\pi}{2} \right)$$

$$v_2 = V_2 \sin (\omega_2 t + \varphi)$$

taking as a reference phase that of voltage v_1 .

Diodes 7 and 8 which might be replaced by other types of rectifiers, suitably biased by battery B₁, and

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whose anode circuits are respectively loaded by one winding 9₁ or 10₁ of relay 9 or 10, play the roles of the above mentioned mixers. 9₁ and 10₁ are shunted by capacitors C₁ and C₂ by-passing high frequency currents according to the usual practice. The voltages respectively applied to the cathodes of the mixer diodes 7 and 8 are, respectively, equal to

$$v_1 + v_2 = V_1 (\sin \omega_1 t + m \sin (\omega_2 t + \varphi))$$

$$v_1' + v_2 = V_1 \left(\sin \left(\omega_1 t + \frac{\pi}{2} \right) + m \sin (\omega_2 t + \varphi) \right)$$

It will be assumed that the ratio $m = V_2/V_1$ is essentially less than unity.

According to a result given in a paper by E. B. Moullin on "Detection by a Straight-Line Rectifier of Modulated and Heterodyne Signals," published in the review "Wireless Engineer," July 1932, pp. 378-383, the expression for $(v_1 + v_2)$ may be written:

$$V_1 \sqrt{1 + m^2 + 2m \cos (\Omega t - \varphi)} \cdot \sin (\omega_1 t - A)$$

designating by Ω the difference $(\omega_1 - \omega_2)$. In the latter expression A is not a constant, but a function of time depending on Ω and m . This quantity A represents the frequency modulation utilized in the Crosby system already referred to and plays no part in the present invention as, the value of m being small, A itself is small and has no appreciable effect on the performance of the system.

After rectification by diode 7 biased by B₁ so as to eliminate any permanent direct current component, there is obtained, at point a on the load of diode 7 constituted by the winding 9₁ of relay 9 a voltage

$$e_1 = E \cos (\Omega t - \varphi)$$

together with its harmonics. The amplitudes of the latter are small enough to be negligible if $m = V_2/V_1$ is definitely less than unity (for instance if m is less than 0.4 it can be shown that the relative amplitude of the second harmonic is less than $m/4$ i. e. less than 0.1).

Similarly, at point c of the load circuit of diode 8 and across the winding 10₁ of relay 10, there is found a voltage e_2 equal to

$$e_2 = E \cos \left(\Omega t + \frac{\pi}{2} - \varphi \right)$$

The corresponding magnetic fields in the magnetic circuits of relays 9 and 10, may be expressed in the form Ke_1 and Ke_2 K being a constant.

Leaving out of account, in the diagram of Figure 2, elements 13, 13', 14, 14' the function of which will be explained later, there is found, between point a and ground, a capacitor-resistor circuit C, R, which effects the differentiation of e_1 with respect to time (the elements C and R being suitably calculated in terms of the frequency differences which may be expected). An identical circuit C', R', arranged between point c and ground, effects the differentiation with respect to time of voltage e_2 .

At points b and d of Figure 2, i. e. at the control grids of triodes 11 and 12, signals voltages appear which are, substantially

$$RC \frac{de_1}{dt}$$

and

$$RC \frac{de_2}{dt}$$

Triodes 11 and 12 have their control grids negatively biased by battery B₂, so that their anode currents are very nearly zero in the absence of a signal applied to the control grid. The anode of tube 12 is loaded by a second winding 9₂ of the relay 9 and the anode of the tube 11 by a second winding 10₂ of the relay 10. Thus there appears, in the second winding of the relay 9 a voltage kde_2/dt which causes in the magnetic circuit of relay 10 a magnetic field $Kkde_2/dt$ which adds to the magnetic field Ke_1 caused by

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the voltage e_1 across the terminals of its first winding. The resulting magnetic field is proportional to the above defined quantity S_1 . Similarly, the total magnetic field applied to the magnetic circuit of relay 10 is proportional to the quantity S_2 i. e. to the sum of the magnetic fields $K e_2$ and $K k d e_1 / dt$. Thus the required adding process for forming S_1 and S_2 is materialized in the addition of the fields in the magnetic circuits of relays 9 and 10.

When the frequency of the controlled oscillator is lower than the reference frequency, it has been seen that the amplitudes of signals S_1 and S_2 are respectively $(1-k\Omega)KE$ and $(1+k\Omega)KE$.

It is easy to select a maximum value of the factor $(1+k\Omega)$ below which the amplitude of S_2 is insufficient for causing the relay 10 to attract its armature. As an example, this relay may be designed so that it operates when the quantity S_2 reaches the value 1.5 KE. Taking, for instance, for k (which depends on the amplification of triode 11) a value equal to 2, for instance, nothing will happen so long as the absolute magnitude of $\Omega = (\omega_1 - \omega_2)$ is less than 0.25, i. e. as long as the controlled frequency is equal to the reference frequency within less than one cycle is about 25 seconds. (As $\Omega = 2\pi \times$ frequency of beats.) But as soon as the controlled frequency decreases so that the difference exceeds this value, the relay 10 will attract its armature, closing the circuit of the line L_2 which delivers to the motor 15 a control signal causing it to rotate in the proper direction for correcting the frequency of oscillator 2 and so decreasing Ω , and, consequently, the amplitude of S_2 .

If, on the contrary, the controlled frequency is too high, the quantities S_1 , S_2 interchange their values and if the frequency difference is large enough, it is the relay 9 which attracts its armature, closing the circuit of line L_1 which delivers to the motor 15 a control signal causing it to rotate in a direction opposite to the previous one, which has the effect of decreasing the frequency of the controlled oscillator 2 and consequently the magnitudes of Ω and S_1 .

In the case of a first starting of the apparatus or of a sudden variation of one of the two frequencies, it might happen that the difference Ω be large enough for causing that one of the quantities S_1 and S_2 which is equal to $(1-k\Omega)KE$ to take a high negative value, and if relays operating indifferently for both possible directions of their magnetic field are employed, this would result in simultaneous operation of both relays.

To avoid inconvenience possibly resulting from this phenomenon there are provided between the anodes and control grids of triodes 11 and 12, series resistor-capacitor circuits such as 13, 14 and 13', 14', the values of the elements of which are such that the degenerative feedback they introduce in the amplification of the triodes is negligible for normally expected frequency deviations. When, however, the difference Ω suffers a large increase, feedback begins to appear and the simultaneous variation of amplitude and phase of the anode-grid feedback voltage causes the actual amplification of the said triodes to decrease accordingly.

With the help of the above described device it is possible to ensure the correct operating of the desired relay and of this relay alone within a fairly wide range of values of Ω for instance varying in a ratio of 1 to 10 and even more.

The device may also be very useful if the method just described is used no longer for correcting the frequency of an oscillator but only for giving an alarm indicating a difference between the two compared frequencies.

It should be noted that the very principle of the method sets a certain limit to the extent of the range of frequency differences within which the apparatus will operate correctly. If, for instance, the value of the deviation Ω becomes much larger than that for which the elements have been designed, the CR network will no longer effect a true differentiation with respect to time and the phase rotation which is one result of this differentiation will decrease as Ω increases, with the result that the amplitude difference

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between quantities S_1 and S_2 will tend to become lesser and lesser.

The dimensioning of C and R and C' and R' should therefore be determined as a function of the normally expected differences between the controlled and reference frequencies in such a manner that the product $RC\Omega$ remains, for instance, even in the most unfavorable case, less than unity.

The sensitivity of the apparatus can be made all the higher as the oscillators used are more stable. The method is especially suitable for the adjustment and control of frequency substandards by comparison with a high stability standard.

Figure 3 shows another embodiment of the invention in which the addition of each one of the voltages e_1 and e_2 with the time derivative of the other one is no longer effected in relays but by means of electron tubes provided with three electrodes or more. In the diagram of Figure 3, such an embodiment, using two triodes 16 and 17, is shown. As in the case of Figure 2, beat voltages are supplied by diodes 7 and 8. These voltages are applied to the cathodes of 16 and 17 while, by means of the differentiating circuit C', R' a signal, proportional to the time derivative of voltage e_1 , developed across the terminals of resistor 18 is applied at point b to the control grid of triode 17, to the cathode of which is applied voltage e_2 supplied by diode 8 across resistor 19. Similarly, triode 16 is subjected to two control voltages, one of them e_1 as already explained, the other one applied through circuit C, R to its control grid at point d and proportional to the time derivative of voltage e_2 rectified by diode 8 across resistor 19. The triodes 16 and 17 are biased by battery B_3 so that their anode currents are low in the absence of applied signals. Their anode circuits are fed from battery B_2 through impedances 20 and 21 the nature of which is not specified in the diagram and which may be those of relays closing control lines like L_1 and L_2 , in Figure 2, when the current flowing through their windings exceeds a predetermined intensity, or else field windings of a motor (like motor 15 in Figure 2) which would start in one or the other direction when one of its windings is energized by a current of sufficient intensity. In the example of Figure 3 the control signals S_1 and S_2 defined above, are respectively the anode currents of triodes 16 and 17. Condensers 13' and 19' filter out high frequency currents, in the same way as C_1 and C_2 in Figure 2.

What I claim is:

1. A device for stabilizing the frequency of a controllable frequency oscillator with respect to that of a constant frequency voltage source, comprising mixer circuits including means for obtaining from said oscillator and source first and second substantially sinusoidal beat voltages phase-shifted with respect to each other by substantially ninety degrees, means for obtaining from said beat voltages first and second derived voltages respectively proportional to the time derivatives of each one of said beat voltages, first and second electron tubes each having a cathode, an anode and a control grid, biasing means for applying between said grids and cathodes direct-current voltages to prevent anode current flow through said tubes when no signal is applied to said grids, means for respectively applying to the control grids of said first and second tubes said first and second derived voltages, first and second electromagnetic relays each provided with at least one winding, means for impressing upon the winding of said first relay a current proportional to said first beat voltage and the anode current of said second tube, means for impressing upon the winding of said second relay a current proportional to said second beat voltage and the anode current of said first tube, and contacts actuated by said relays and operating a control mechanism controlling the frequency of said controllable frequency oscillator.

2. A device as claimed in claim 1, wherein each of said relays is provided with two windings, one of which con-

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ducts the corresponding anode current and the other of which is submitted to the corresponding beat voltage.

3. A device as claimed in claim 1, wherein each one of said relays is provided with a single winding conducting the anode current of the corresponding tube, and wherein a current proportional to the corresponding beat voltage is obtained by applying said beat voltage to the cathode of the corresponding tube.

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