APPLICATION OF THE UHF TECHNIQUE FOR CONTACTLESS MEASUREMENT OF THE SPEED OF ROTATION

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It is advantageous in many instances to use UHF techniques for contactless measurement of various parameters such as vibrations, speed of rotation, etc. of moving components in mechanisms. Moreover, it is convenient to use the Doppler effect which, as is known, produces variations in the frequency of electromagnetic waves reflected from moving surfaces.

Assuming the conditions of electromagnetic wave reflection to be constant and taking into consideration that in such a case phase variations depend on the changes in the distance $L$ to the reflecting object, it is possible to write the following expression for the phase:

$$\varphi = \frac{4}{\lambda} \pi L.$$  \hspace{1cm} (1)

In a steady-state condition variations in the distance will amount, according to (1), to

$$L(t) = L_0 - tv \cos \gamma,$$  \hspace{1cm} (2)

where $L_0$ is the distance at instant $t = 0$; $V$ is the velocity of the reflecting object; $\gamma$ is the angle between the velocity vector and the direction of wave propagation.

The coefficient 4 in the numerator of (1) takes account of the fact that a reflected wave travels double the distance; the product $V \cos \gamma = V_d$ in (2) determines the speed of the reflecting object in the direction of the radiated propagation (Fig. 1).

If a harmonic signal of frequency $f$ is radiated, the reflected signal can be written as

$$E_r = E \cos (\omega t - \varphi) = E \cos \left[ \omega t - \frac{4\pi}{\lambda} (L_0 - Vt \cos \gamma) \right]$$

$$= E \cos \left[ \left(2\pi f + \frac{4\pi}{\lambda} V \cos \gamma \right)t - \frac{4\pi}{\lambda} L_0 \right].$$

Henceforth the constant phase difference $\varphi = 4\pi L_0/\lambda$, which characterizes initial conditions, can be omitted. It follows from (3) that the frequency of the received signal is

$$f_r = f + \frac{2}{\lambda} V \cos \gamma,$$

and differs from the transmitted frequency by the value of the Doppler effect

$$f_d = \frac{1}{2\pi} \cdot \frac{df_r}{dt} = \frac{2}{\lambda} V \cos \gamma,$$

where

$$f_d = f_r - f.$$  \hspace{1cm} (4)

It will be seen from (4) that the difference frequency $f_d$ is proportional to the reflecting surface velocity component which is in the direction of wave propagation.

In order to produce the Doppler effect by irradiating a rotating shaft it is necessary that it should have some irregularities instead of a smooth mirror surface. If we assume that $\gamma = 0$, i.e. if we use a linear model, the signal reflected from $i$ irregularities placed at a distance $l_i$ can be represented for a steady-state condition by

$$E_r = \sum_i E \cos \left[ \left(\omega + \frac{4\pi}{\lambda} V \right) t + \varphi_i \right].$$  \hspace{1cm} (5)
where $\varphi_{1} = 4\pi l_{1}/\lambda$ does not depend on time, and the adding takes place in all the $i$ elements, which means that the reflected signal is formed by all the elements in the irritated region at each instant. It will be seen from (5) that the reflected signal represents a summation of sine waves with the same difference frequency. By considering a general case of a difference frequency determined by the Doppler effect instead of a linear model where angle $\gamma = 0$, we revert to equation (4).

Under operating conditions the mechanism for forming reflected signals becomes more complicated by the fact that the beam of electromagnetic energy directed onto the reflecting surface has a definite width, thus producing a reflected signal which is not strictly monochromatic, since the angle of incidence within the beam varies. The spectrum of such a signal is continuous and has a certain width, and its middle corresponds to the frequency

$$f_{d, 0} = \frac{2}{\lambda} \cos \gamma_{0},$$

(5a)

where $\gamma_{0}$ is the maximum radiation angle.

The width of the frequency spectrum is

$$df = \frac{2}{\lambda} V \sin \gamma d\gamma,$$

(5b)

or, in terms of finite increments,

$$df = \frac{2}{\lambda} V \sin \gamma_{0} \Delta\gamma.$$

(6)

The latter expression is approximate, since it does not take into consideration the radiation pattern; however, within the limits of an angle corresponding to half the power the application of (6) is completely permissible.

From the above equations, and in particular from (4), it follows that the beat frequency for fixed values of $\lambda$ and $\gamma$ is proportional to the linear velocity of the irritated component of the mechanism. If the dimensions of the rotating irritated component are known, the linear velocity and the speed of rotation have a single-valued relationship which is taken as the basis of the above method.

In designing instruments operating with continuous radiation it is necessary to have a separating device between the generator and the receiver channels. This part of the circuit should provide a maximum transfer constant from the generator to the antenna and from the antenna to the receiving device, transmitting at the same time a minimum direct signal from the generator to the receiver. The most simple solution consists in the use of a twin-T connection which introduces a separation loss of 6 db. More complicated separating devices which have smaller losses are described in [1].

The schematic of an instrument for measuring the speed of rotation with a separating device in the form of a twin-T connection is shown in Fig. 2. The UHF power is fed from the klystron generator through the decoupling attenuator to the separator where it is divided into half and transmitted to the rotating or vibrating surface and to a matched resistance. The drawback of this circuit consists in the critical matching of the T bridge, thus leading to an increase in the direct power which seeps through from the generator to the mixer and, hence, to a deterioration in the linearity of the receiving channel if the circuit is not carefully tuned.

Improved linearity can be attained with the circuit (Fig. 3) which uses a directional coupler and has a separating device. Losses in such a circuit amount to approximately 5-10 db. A well-made coupler has a directional discrimination of 30-35 db [2], thus reducing considerably the direct signal transmitted from the generator to the crystal mixer. The use of a balanced mixer reduces the effect of stray amplitude modulation, thus improving conditions for certain types of measurements.

These circuits (Figs. 2 and 3) can be used for noncontact measurements of the speed of rotation; moreover, the irregularity for producing the Doppler effect can consist of a gear wheel, a worm transmission or similar devices which