A SHOCK-EXCITATION STUDY OF THE PERFORMANCE OF STUB SLOW-WAVE SYSTEMS

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Shock excitation (as used with high-Q cavities) is employed to test slow-wave systems, including ones of low Q. Results are given for stub systems tested in this way.

Many UHF devices employ an electron beam moving in step with a slow wave. Stub systems are of interest here as they provide strong interaction between the beam and the field [1]. The strength of the interaction may be evaluated via the coupling impedance, while the dispersion parameters characterize the matching of the two velocities [1-4].

Stub systems are also used in accelerators, especially waveguide separators and synchrotrons, which employ various such systems [5-7]. Here the coupling is governed by the shunt resistance [6, 8, 9], which is a function of the electric field and of the attenuation coefficient (i.e., of the coupling impedance and Q).

It is not always necessary to verify the theoretical values for the coupling impedance in electronic devices, but experiment is the only way of determining this impedance at present for the stub systems used in waveguide synchrotrons, where the theoretical Q [6] may be far larger than the measured one [10].

The measurements usually made on slow-wave systems are the dispersion, the coupling impedance, and the Q; the dispersion curves (retardation γ as a function of frequency or wavelength) for a resonant system are found simply from the resonance frequencies and the field distribution at those frequencies. The frequencies are best determined by oscilloscope [11] via the use of frequency-modulated oscillators. The distribution and coupling impedance may be determined by the use of small perturbing bodies [12] or with absorbers (by attenuation) [13, 14]. In the first case the resonance frequency is altered by an amount Δf_p, while in the second the lossy probe reduces the field amplitude.

It is rather difficult to combine the oscilloscope methods for Q [11, 15] with those for the dispersion, and the techniques can be simplified only if the dispersion, impedance, and Q are measured in essentially the same way. The simplest way of doing this is to employ the damping curve following shock excitation [16] (decrement measurement), which has been applied for Q above 30 000 [11], 50 000 [15], 10 000 [17], and about 9000 [18], the last at 9300 Mc. The system is excited by a UHF pulse, and the time-constant of the decay defines Q. This decay is very fast if Q is low, which makes the determination inaccurate, which is why the method is usually confined to Q of over 10 000. The accuracy then increases with Q.

There are two distinct ways of applying this method to high-Q systems [11, 15, 17, 18]: direct measurement of the time for decay by a factor e and use of a fixed attenuation with a time decay. Neither is directly applicable to a low-Q system, but the following technique allows one to apply the method for Q from 10 000 down to a few hundred.

The field in the cavity at a time t after the end of the pulse is [11] given by

$$i = i_0 e^{-\frac{\pi f t}{Q}}, \tag{1}$$

in which i_0 is the current at the end of the excitation. Figure 1a shows square pulses of length τ applied to modulate the UHF source; Fig. 1b shows the observed transients. Q is given by (1) as

$$Q = \frac{\pi f t}{\ln \frac{i_0}{i}}. \tag{2}$$

The main difficulty for Q low arises in determining the i_0/i and t required in (2); there is no difficulty in measuring the resonant frequency f. The level i must be determined in order to find i_0/i, for which purpose I have used a negative-going pulse applied at time t to the z modulator of the oscilloscope (Fig. 1c). This gives the transient pattern shown in Fig. 1d (or, for n pulses, in Fig. 1e). The i level is thus determined precisely on the oscilloscope.

Figure 2 gives the block diagram of the apparatus. The modulator was a 26-I square-pulse generator with bipolar output, the positive-going pulse being applied to the UHF oscillator and the negative-going one (delayed by a time $T = \tau + t$) to the z modulator of the EO-7 oscilloscope. This t is necessarily small, so it cannot be measured with adequate accuracy each time a Q is to be measured; but t and τ may be kept constant between measurements (fixed total delay T), which gives an indirect method for t by the use of any standard cavity (one with a known Q). Then (2) gives t as

$$t = \frac{Q \ln \frac{i_{0s}}{i_s}}{\pi f_s}. \qquad (3)$$

Then i_0/i is found from the oscilloscope; a linear detector gives $i_0/i = A_0/A$, in which A_0 and A are the deflections at the screen proportional to i_0 and i. A square-law detector gives

$$\frac{i_0}{i} = \sqrt{\frac{A_0}{A}}. \qquad (4)$$

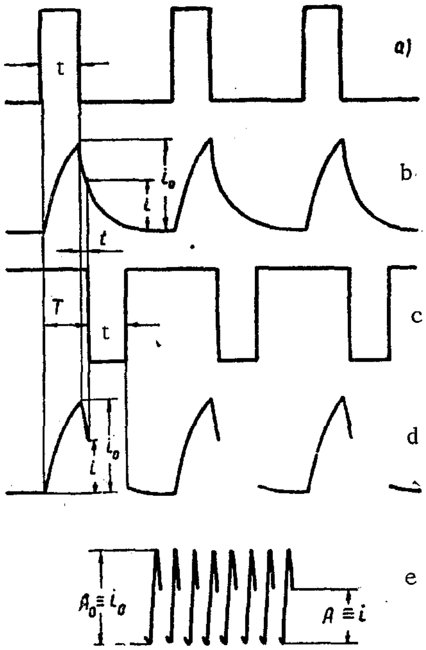

Fig. 1. Use of the transient response in a low-Q system.

In practice, it is more convenient to use the following expression than to employ (3) and (2); it is derived from (2) by putting T = constant:

$$\frac{Q_1}{Q_2} = \frac{f_1}{f_2} \cdot \frac{\lg N_2}{\lg N_1}, \qquad (5)$$

in which $N = (A_0/A)^{1/2}$.

Then (5) gives Q_x for the system (resonance frequency f_x) in terms of that of the standard cavity Q_s (resonance frequency f_s) as

$$Q_x = Q_s \cdot \frac{f_x}{f_s} \cdot \frac{\lg N}{\lg N_x} = \kappa \frac{f_{px}}{\lg N_x}, \qquad (6)$$

in which $\kappa = Q_s \lg N_s / f_s$.

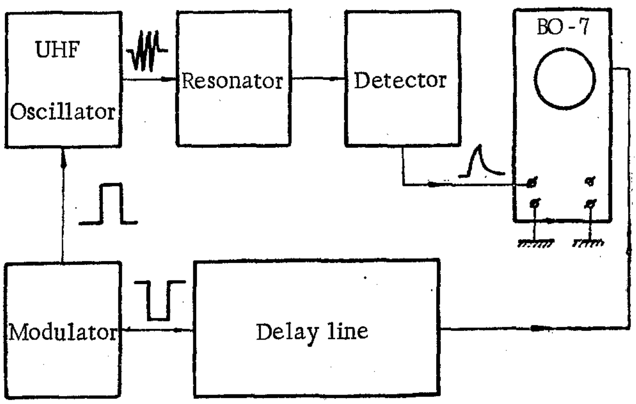

Fig. 2. Block diagram of the shock-excitation apparatus for low-Q systems.

The over-all error resembles that of other oscilloscope methods and does not exceed ±5%, or rather less if the measurements are made with considerable care.

Calibrated T and t, with a standard cavity, thus makes it possible to measure Q above and below 10 000. The over-all error is minimized if the standard cavity resembles the unknown, i.e., if $|Q_1/Q_2|_{max}$ is 2-3.

I have tested these conclusions on two slow-wave systems; one with a double series of slots and ridges (a = 20 mm, b = 10 mm, w_1 = 16 mm, w_2 = 6 mm, $h_1 = h_2 = h$ = 11 mm, p = 30 mm, q = 20 mm) and the other with two opposing rows of stubs (a = 28.8 mm, b = 10 mm, w = 10 mm, h = 21 mm, g = 9 mm, p = 35 mm, q = 10 mm), as in Fig. 3. The standard was a 34 × 70 × 72 rectangular cavity resonating at 2980 Mc in the H_{101} mode having Q_s = 3500 and $\lg N_s$ = 0.287. The table gives the results, which are compared with those from the impedance method.

System	Mode ψ	f, Mc	$\lg N_x$	Q	
				Shock	Impedance
Fig. 3a	π	2900	0.46	2120	2300
Fig. 3b	$\frac{2\pi}{3}$	2690	0.40	2300	2500
	π	2800	0.368	2550	2600

The discrepancies are within the error of experiment, so this method for low-Q systems may be used to advantage as follows:

1. The resonances are located with an oscilloscope by reference to the maximum transient response.

2. The modes are identified from the effects on the amplitude when a probe is tracked through the system. The amplitude is reduced either due to a change Δf in the resonance frequency (small perturbation method) or to absorption (absorber method).

3. Q is determined as above.

4. The coupling impedance is deduced from the design of the probe (as in the identification of modes), from Δf, or from the fall in Q produced by the probe.

These methods of measuring the coupling impedance may be used in combination to give a very flexible technique for examining slow-wave systems; but small Δf cannot be measured with sufficient precision with wavemeters, which may require the use of much more complex heterodyne methods for Δf. The absorber method involves measurement of Q alone, so it is to be preferred.

5. The shunt impedance is deduced from Q and the coupling impedance in accordance with published expressions [5, 6, 8].

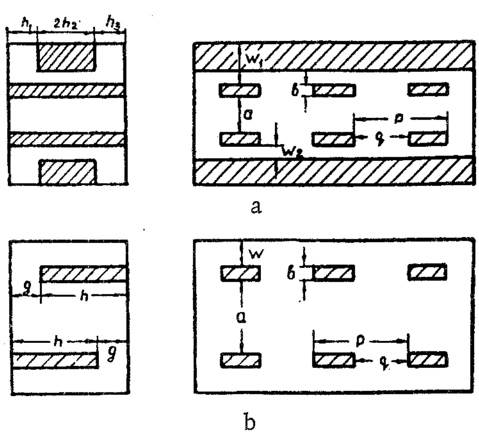

Fig. 3. Stub slow-wave systems: a) two rows of slots and ridges; b) opposing rows of stubs.

I have used this method to examine a system differing from that of Fig. 3b in having both sets of stubs attached to one wide side of the guide only. This system was tested for the following reasons. These two-row systems have a higher coupling impedance than do one-row ones [1]; in addition, the two-row type used here is of greater interest in relation to iron-free waveguide synchrotrons, in which the periodic structure may be attached to (or even cut into) the current leads.

In this case it is desirable to determine the range of wavelengths that can be handled with stubs roughly as above: (a = 20 mm, b = = ω = 10 mm, p = 40 mm, q = 30 mm). Only the effects of height h and gap g were therefore examined. The necessary expressions for the wave admittances and end capacitances are given in [19], which were derived by an electrodynamic method analogous to that of [20].

The dispersion was computed on a Minsk-1 computer on the basis of five spatial harmonics (S = 0, ±1, ±2) and five higher modes. The width of the dispersion curve for the antiphase waves is much less than that for the in-phase ones; moreover, the modes for these (the former being reckoned as parasitic relative to the latter) are different in wavelength (the antiphase ones lie at shorter wavelengths), so there is no superposition of modes such as occurs in systems such as that of Fig. 3a [10] or Fig. 3b [21].

Figure 4a has been kept fairly simple by showing only the curve for h = 15 mm for the antiphase waves (on the left), together with curves for the synphase ones for h of 13, 15, 17, and 19 mm. Figure 4b gives theoretical dispersion curves only for g = = 27 mm, for the same reason. The experimental curves of Fig. 4 are displaced to longer wavelengths, but the deviation from theory is less than 2%. One reason for this is that the end capacitances are frequency-dependent, so successive approximation had to be used in the calculations, and the calculated curves represent only the second approximation. Test calculations for a few points show that the third approximation gives less than 0.5% error, and the fourth less than 0.1%.

The dispersion curves show that it is possible to produce wavelengths considerably exceeding 4h; for instance, for h = 19 mm we have $\lambda_{\psi=\pi} \simeq 6h$, and $\lambda_{\psi=0} \simeq 9h$, which represents a very broad-band system. The curves move steadily to longer wavelengths as h is increased, as one would expect.

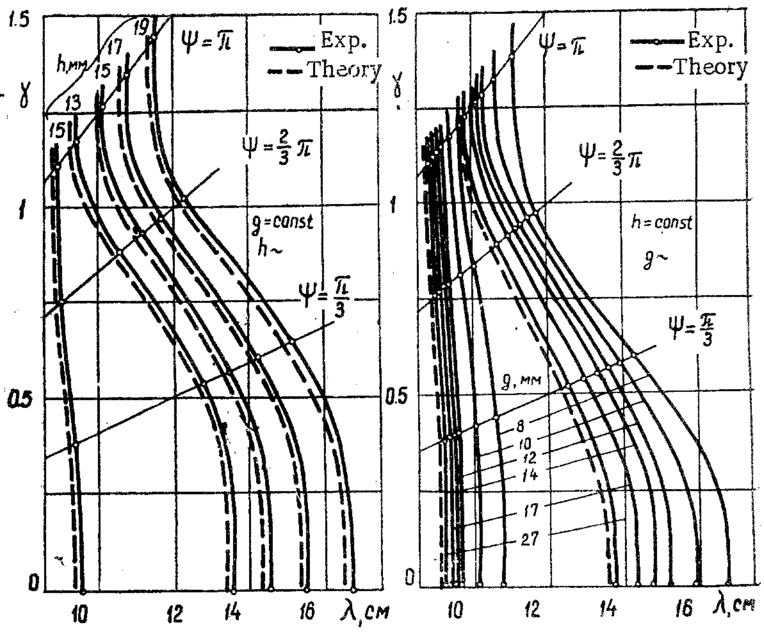

Fig. 4. Dispersion curves for the experimental system: a) g = 11 mm = const, b) h = 16 mm = const.

Figure 4b shows that g affects the working mode only for g < h; the Q and coupling impedance are then (Fig. 5) appreciably altered only if g is brought to some optimal value around 1.5 h, above which g hardly affects the result.

The Q increases roughly exponentially with h for the above dimensions, presumably on account of more rapid increase in the stored energy than in the losses. The coupling impedance was measured at all times in the standing-wave condition for $\psi = \pi$ at the center between the rows of stubs at a height of 10 mm, so it decreases as h increases.

The shunt impedance was 25 kΩ/cm for $\gamma = 1$, h = 19 mm, and g = = 11 mm; it was 20 kΩ/cm for $\gamma = 1$, h = 16 mm, and g = 8 mm.

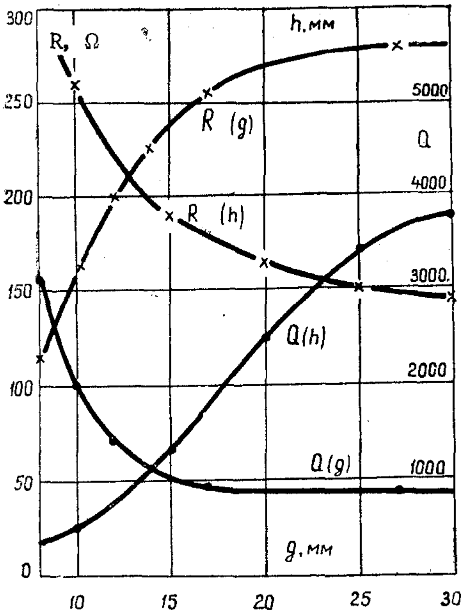

Fig. 5. Relation of coupling impedance and Q to stub height and gap.

Conclusions

An oscilloscope method for shock excitation has been developed and tested on resonant systems. This method is simple and employs only one type of measurement; it rapidly yields much information. This method for Q greatly extends the range of application of shock excitation and can be used with a variety of cavity shapes over a very wide range in Q. The results given here on stub systems are of value in UHF generally, as well as in accelerator technology.

REFERENCES

1. Yu. G. Al'tshuler and A. S. Tatarenko, Low-Power Backward-Wave Tubes [in Russian], Sovetskoe Radio, 1963.
2. J. R. Pierce, Travelling-Wave Tubes [Russian translation], Sovetskoe Radio, 1952.
3. I. V. Lebedev, UHF Technique and Device [in Russian], vol. 1, Gosernergoizdat, 1961.
4. W. Kleen and K. Pöschl, Einfürung in die Mikrowellen Electronik, Part II, 1958.
5. A. A. Vorob'ev and A. N. Didenko, Atomnaya energiya, 12, no. 3, 342, 1962.
6. A. N. Didenko and Yu. A. Panov, Izvestiya VUZ. Radiofizika, no. 5, 187, 1962.
7. L. N. Bezmaternykh and P. I. Gos'kov, Summaries of Papers at the Fifth Intercollegiate Conference on Accelerators [in Russian], Tomsk, 1964.
8. A. N. Didenko and E. S. Kovalenko, Atomnaya energiya, 10, no. 1, 69, 1961.
9. O. A. Val'dner and A. V. Shal'nov, Electromagnetic Waves in the Waveguides of Linear Electron Accelerators [in Russian], Gosatomizdat, 1963.
10. P. I. Gos'kov, Izvestiya VUZ. Radiofizika, no. 5, 1964.
11. E. L. Hinston, Measurements at Centimeter Wavelengths [Russian translation], IL, 1960.
12. G. N. Rapoport, Radiotekhnika, 12, no. 2, 51, 1957.
13. Electromagnetic Slow-Wave Systems [in Russian], Trudy MAI, no. 125, 1960.
14. S. N. Tetel'baum, G. I. Gladyshev, and G. N. Rapoport, Trudy Inst. Elektrotekh, AN UkrSSR, 12, 1955.
15. R. A. Valitov and V. N. Sretenskii, UHF Radio Measurements [in Russian], Voenizdat, 1958.
16. P. I. Gos'kov and P. I. Matyazh, Shock-Excitation Method for Low-Q Cavities, Accepted by the Committee on Inventions and Discoveries from Application No. 915 269/26-9, class $21a^4$, 71, 20 October 1964.
17. Measurement Techniques at Centimeter Wavelengths [in Russian], vol. 1, 1949.
18. E. I. Kulikov, Izmeritel'naya tekhnika, 6, 1959.
19. L. N. Bezmaternykh, Dissertation, Tomsk, 1964.
20. E. S. Kovalenko and V. S. Kovalenko, Radiotekhnika i elektronika, 8, no. 8, 1963.
21. P. I. Gos'kov and L. N. Bezmaternykh, Radiotekhnika i elektronika, no. 5, 1965.

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