On the Interaction of Two Plane Shocks Facing in the Same Direction

OTTO LAPORTE AND E. B. TURNER
Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan
(Received January 4, 1954)

THE problem of the coalescence of two shocks has been given considerable theoretical attention in the literature. First treated by von Neumann[1] and by Courant and Friedrichs,[2] this case of shock interaction was calculated in considerable detail by Bull, Fowell, and Henshaw.[3] The time sequence of events is as follows. First there must be two shocks separated by a region of constant flow; at the moment when the rear shock reaches the front shock, as it always must, there is formed a stronger shock of coalescence proceeding in the same direction as well as an interface which moves with the flow and a centered rarefaction which moves backwards. For γ larger than 5/3, a case which will not be considered further here, the rarefaction may be replaced by a weak shock facing in the direction opposite to the amalgamated shock.

As far as we know this phenomenon has up to now escaped observation in shock tubes. We should like to report a method which makes it possible to create two equally facing shocks separated by a constant state. This is accomplished by blocking the test section with a comblike stack of plates spanning the width of the tube (see Figs. 1 and 2). Evidently the wedgelike tips will, when struck by the incident shock, give rise to cylindrical reflected shocks which quickly, by Huygens principle and Mach interaction, form the first plane shock. In the meantime segments of the primary shock travel down into the interstices, are reflected at the ends, and on emergence form a second plane shock. The strengths of these two similarly facing shocks may evidently be varied between wide limits by (a) varying the strength of the primary shock and (b) varying the ratio of the thickness of the plates to that of the interstices.

The two interferograms shown below were taken with the University of Michigan 2- by 7-inch shock tube, using the 9-inch, 30°–60° Mach-Zehnder interferometer. The gas used was argon, and the shock strength or pressure ratio of the incident shock was 12. Seven plates separated by six spacers of $\frac{3}{8}$-inch thickness were employed. The first interferogram, taken with white light, shows two perfectly formed shocks[4] proceeding away from the stack of plates. The fringe shifts indicate that they possess approximately the same density discontinuity and that they are separated by a region of constant flow. The second interferogram shows at the extreme left the amalgamated shock and its larger fringe shift. Somewhat to the right the interface with its minute fringe shift may be seen. According to the theory, a rarefaction should be present between the interface and the reflecting device, but it is not discernible in our flow pictures. The reason for this is twofold: First, for the shock strengths used here, the density change across this rarefaction is small compared with the density change across the interface (which itself is small in comparison to the density change across the resulting shock). Secondly, inasmuch as plate-glass windows were used on the shock tube, it was not intended to observe the phenomenon in its ultimate refinement at this point. The density changes inferred from the fringe shifts are in accord with the theory within our experimental error. Schlieren photographs, taken of the same process, show the interface with extraordinary sharpness and clarity.

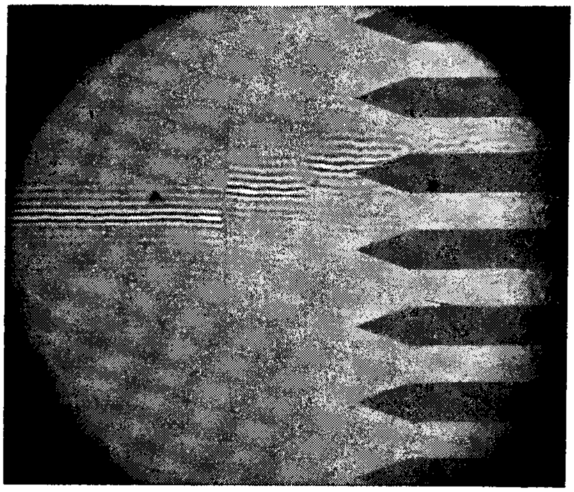


FIG. 1. First interferogram showing the two shocks before amalgamation. The white marks identify the central fringe of the white light fringe pattern.

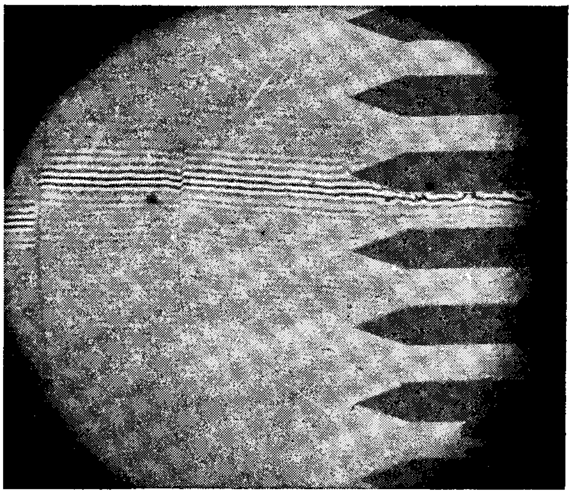


FIG. 2. Second interferogram taken after interaction.

This work was partially supported by the U. S. Office of Naval Research under Contract No. N6-onr-232, T. O. 4, with the Engineering Research Institute of the University of Michigan.

---

[1] J. von Neumann, Progress Report on the Theory of Shock Waves. National Defense Research Committee, Division 8, Office of Scientific Research and Development No. 1140, 1943.

[2] R. Courant and K. O. Friedrichs, Interaction of Shock and Rarefaction Waves in One-Dimensional Motion. National Defense Research Committee, Applied Mathematics Panel Report 38.1R (Applied Mathematics Group—New York University No. 1), 1943.

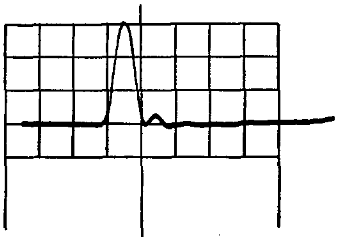
[3] Bull, Fowell, and Henshaw, The Interaction of Two Similarly Facing Shock Waves. Institute of Aerophysics, University of Toronto, UTIA Report No. 25, 1953.

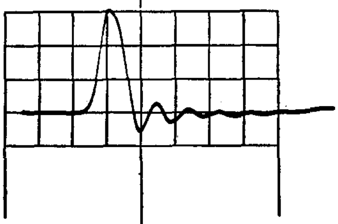
[4] Since the plate stack did not span the height of the tube entirely, but left slightly more than 1 inch at top and bottom, the shocks show a slight curvature, especially at their ends and at the larger distances from the reflecting plates.

High-Speed Magnetic Pulsing of Ferrites

R. CONWAY LECRAW
Diamond Ordnance Fuze Laboratories, Washington, D. C.
(Received December 18, 1953)

A NUMBER of papers have reported Faraday rotations of microwaves using ferrites in wave guides.[1,2] Work has been done by Bryan[3] at The Naval Research Laboratory to determine the limiting speeds of rotation for a given ferrite in connection with high-speed microwave switches. He found that, for a particular NiZn ferrite and method of pulsing, the minimum switching cycle is 0.8 μsec. This limitation was attributed primarily to the recovery time of the ferrite.





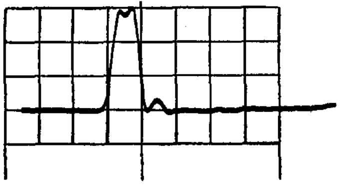


FIG. 1. (top). Video output of detecting crystal, max rotation =90°. The 1.5-db point =one-half the first vertical division.
FIG. 2. (middle). Current I in the coil, max =12 amp.
FIG. 3. (bottom). Video output of detecting crystal, max rotation >90°. The same external triggering pulse was used for all three figures. The time scale =0.025 μsec per division.

Experiments on magnetic pulsing of ferrites at this laboratory have resulted in a switch with a recovery time of 0.012 μsec to the 1.5-db point and a switching cycle of 0.025 μsec between 1.5-db points. The insertion loss is less than 1 db, and the attenuation in the switch-off state is greater than 35 db.

A rod of a MgMn ferrite is placed along the axis of a section of circular wave guide propagating a TE_{11} wave at X band. A longitudinal magnetic field produces a rotation of a linearly polarized wave due to the difference in velocities of the two oppositely rotating circularly polarized waves of which the linear wave is composed.[4] Rotations of 0° and 90° correspond, respectively, to maximum and minimum transmission into a section of rectangular wave guide terminated with the detecting crystal. A piece of resistance card just preceding this section and parallel to its long dimension absorbs the microwave energy in the switch-off state.

An eight-turn coil is wound about the circular wave guide containing the ferrite. A thin axial slit in the guide wall prevents the wall from acting as a shorted turn to the coil. The current I in the coil is produced by a hydrogen thyratron pulser and is monitored by a synchroscope across a 3-ohm coaxial-type resistor in series with the coil. This type resistor has negligible inductive reactance up to several hundred Mc. The current pulse of Fig. 2 produces the video output pulse of Fig. 1 when the maximum amplitude of I is adjusted to produce 90° rotation. The peak magnetizing field is about 18 oersteds. In Fig. 3 a larger amplitude of I produces more than 90° rotation. Some ringing is noted in the current pulse. This can be eliminated if desired. However in these experiments the recovery time of the ferrite switch is of principal interest.

An interesting and somewhat unexpected result is that the ferrite magnetization (to the first approximation proportional to rotation) follows the magnetizing current quite closely. No appreciable time delay in the magnetization process is evident. The time delay of the entire output pulse with respect to the current pulse is due to the length of wave guide between the switch and the detecting crystal. This was checked by using various lengths of wave guide.

Experiments are in progress to study the response of the magnetization of various ferrites as a function of pulse amplitude and length with the latter varying from 0.01 to 0.5 μsec.

[1] N. G. Sakiotis and H. N. Chait, Proc. Inst. Radio Engrs. 41, No. 1 (1953).
[2] C. L. Hogan, Bell System Tech. J. XXXI, No. 1 (1952).
[3] J. W. Bryan (private communication).
[4] R. C. LeCraw, Natl. Bur. Standards Rpt. No. 2313, March, 1953.

Crossed Electron Beam Technique for Measuring Space-Charge Effects in Beams*

PAUL D. COLEMAN, MURRAY D. SIRKIS, AND IRVING KAUFMAN
Electrical Engineering Department, University of Illinois, Urbana, Illinois

(Received December 28, 1953)

SPACE-CHARGE problems associated with the production and bunching of high current density electron beams occupy the attention of many workers in the electronics field. The crossed electron beam technique[1] shows promise as a method of studying space-charge effects in beams in greater detail and with more additional information than, for example, the iris technique of Linder and Hernquist.[2]

The method, as illustrated in Fig. 1, is to probe the high current density test beam by a low voltage swept probe beam and observe the Coulomb scattering on a fluorescent screen. Under the conditions of our experiment, it can be shown that the semiscattering angle θ_0 is given by

$$\theta_0 \simeq \frac{\pi q \sigma(z)}{16 \epsilon m_0 v_0^2}, \tag{1}$$

where $\sigma(z)$ is the charge per unit length of the test beam and v_0, the velocity of the probe beam at the point of crossing. Thus the deflection is proportional to the net charge per unit length, i.e., electron density minus positive ion density, and hence can be used to evaluate directly the positive ion density as a function of time.

The rate of formation of ions per cm³ in an electron beam is given by the expression

$$\frac{dn_2}{dt} = pP(V)n_1v_1, \tag{2}$$

where p is the gas pressure, n_1 the electron density, v_1 the electron velocity, and $P(V)$ the number of ion pairs formed by an electron per unit length at unit pressure[3] (a function of voltage V).

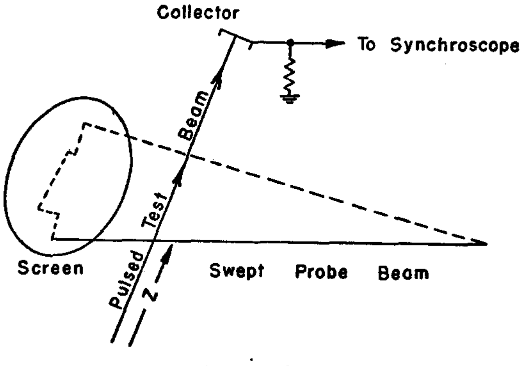


FIG. 1. Crossed electron beam arrangement.