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Time Delay Computer for Precise Control in Recording Transient Events

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Abstract

AN electronic device capable of measuring the speed of an object and providing a signal when that object has moved a predetermined distance has been developed. This time delay computer with digital circuitry is capable of precise and repeatable operation. The tedious, sometimes costly, trial and error adjustments of time delay electronic circuitry used for obtaining photographs of transient events are eliminated. Reliability and repeatability of the time delay computer were very good. However, limitations to the accuracy in predicting the exact position of an object may be introduced by variations in its speed, sensor transducer performance characteristics, and performance of the device used to record its position.

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Operating Principle and Circuit Description

In order to simplify a shock-tube study in which Schlieren photographs were to be the primary data source,[1] a digital time delay computer was designed and constructed to solve the delay determination problem. The device was intended to permit the shock wave's location in each photograph to be predetermined completely independently of its propagation speed, provided only that the speed is constant over some region adjacent to, and upstream from, the camera's field of view. The basic operating principle of the time delay computer is that it first measures the speed of the shock wave as it passes two detectors and then produces an output signal after the period of time necessary for that particular shock to travel the (known) distance from the detectors to the location at which it is to be photographed.

Figure 1 shows the delay computer's operating principle diagrammatically. When the shock passes the first of the two sensors (pressure transducers were used in this case) marked A and B, the resulting electrical signal causes the computer's internal decade up/down counters to begin counting up from zero at a rate determined by the unit's "up-clock" oscillator. This oscillator operates at frequency f_1. When the shock passes sensor B, the up-clock is disconnected from the counters and the "down-clock," a variable-frequency oscillator operating at frequency f_2, is connected in such a manner that each of its pulses is subtracted from the total held by the counters. The time interval required for the shock to pass from the first sensor to the second is Δt_1. The desired delayed output signal is produced when the counters reach zero, by which time an interval Δt_2 has passed.

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From Fig. 1, the velocity/distance/time relationships are

$$u_s = \frac{d_1}{\Delta t_1} \tag{1}$$

$$d_2 = u_s \Delta t_2 = \frac{d_1}{\Delta t_1} \Delta t_2 = \frac{\Delta t_2}{\Delta t_1} d_1 \tag{2}$$

But note also

$$\frac{\Delta t_2}{\Delta t_1} = \frac{f_1}{f_2} \tag{3}$$

Therefore,

$$d_2 = \frac{f_1}{f_2} d_1 \qquad f_2 = \frac{d_1}{d_2} f_1 \tag{4}$$

Thus, the desired location of the shock wave relative to the sensors at the time the output signal is generated is determined only by the ratio of the clock frequencies f_1 and f_2 and the distance between the two sensors, provided that the shock speed remains constant. As long as this last qualification is met, there are no restrictions on the relationship between the sensor separation and the distance from the second sensor to the shock's location when the picture is taken. However, the relationship between this separation d_1, the speed of the shock

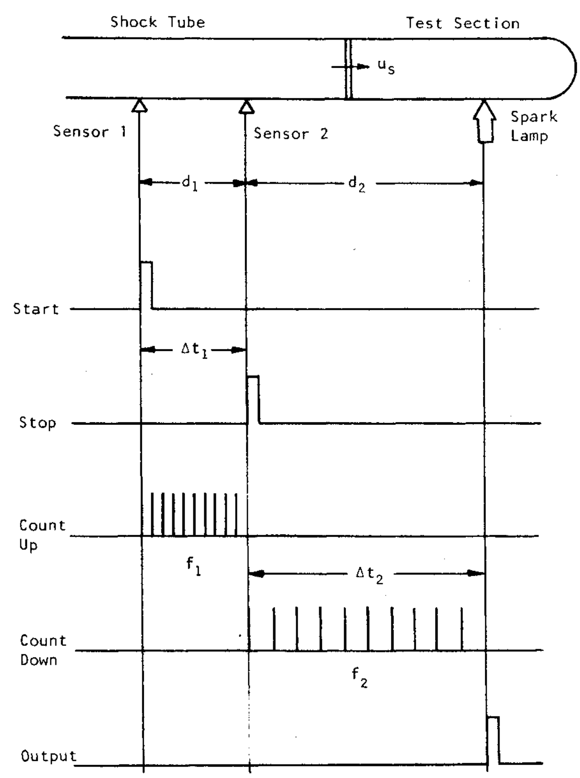

Fig. 1 Time delay computer operation.

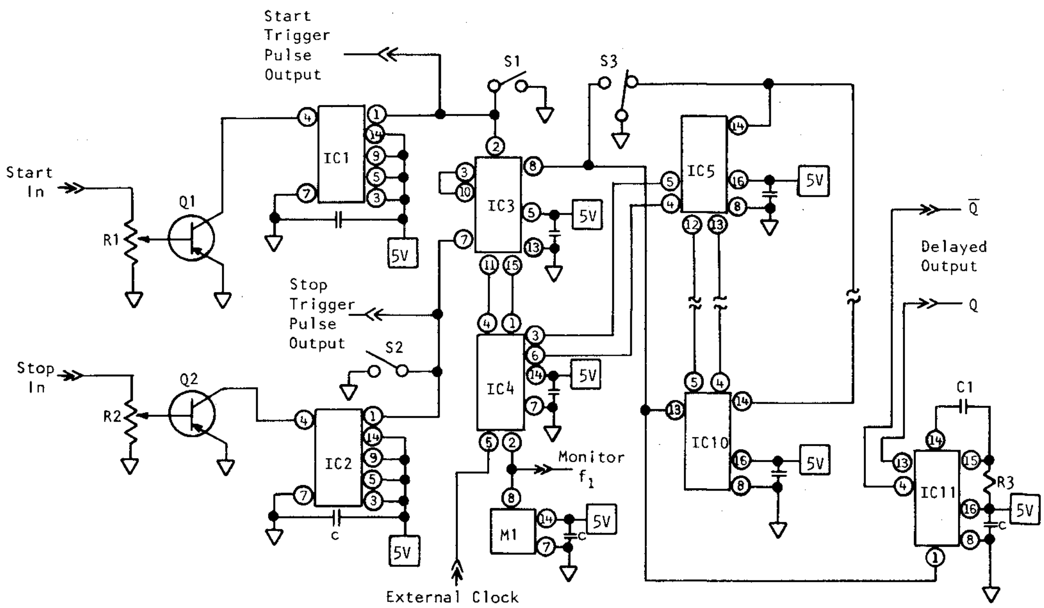

Fig. 2 Time delay computer schematic.

u_s, and the number of clock pulses that can be counted while the shock traverses that distance will affect the overall accuracy. The greater the number of pulses, the greater the potential shock positioning accuracy.

The device constructed uses an up-clock oscillator operating at 10 MHz so that, with an actual shock speed of 914.4 m/s (3000 ft/s) and a sensor separation d_l of 5.08 cm (2 in.), the shock's location when the delayed output signal is produced can theoretically be predetermined to an accuracy of ± 0.009 cm (0.0036 in.). This number is based on the conventional digital logic assumption that relevant input and output events occur within plus or minus one clock pulse.

Figure 2 is a schematic diagram of the time delay computer as constructed in brassboard version for the shock-tube experiment. Transistors Q1 and Q2 serve as input buffers and inverters to convert the positive-going pressure transducer output signals to negative-going transitions required by IC1 and IC2. They are operated as saturated switches in which the minimum "on" input voltage is set by the base-circuit voltage dividers formed by R1 and R2.

Integrated circuits IC1 and IC2 are one-shot multivibrators wired to produce a single 30-ns output pulse each time their inputs go low. IC1 and IC2 fire only once during each shock passage. IC1's output pulse is generated when the incident shock passes sensor A, signifying the beginning of shock speed measurement. The pulse is coupled to the PRESET input of IC3A, one-half of a dual flip-flop. IC3A's Q1 output is ANDED with the up-clock oscillator in IC4A, one-fourth of a quad NAND gate, and, upon transition, applying the oscillator signal to the COUNT-UP input of the six decade BCD up/down counter chain formed by IC5 through IC10.

When the shock wave's passage causes an output from sensor B, IC2's one-shot pulse PRESETs IC3B, the $\overline{Q2}$ output of which CLEARs IC3A, thus disconnecting the up-clock oscillator from the counter chain. IC3B's Q2 output is ANDED with the variable down-clock oscillator in IC4B, so that this clock signal is applied to the counter chain COUNT DOWN input within one clock pulse of the up-clock's disconnection.

The BORROW OUT output of the counter chain's most significant digit counter, IC10, is connected both to IC3B's CLEAR input and to the CLOCK input of IC11, a one-shot multivibrator wired for a single 50-μ sec output pulse. When the counter chain reaches zero after counting down from the up-clock total at the rate determined by the down-clock frequency, IC10's borrow-out pulse simultaneously disconnects the down-clock from the chain and produces the system's delayed output pulse through IC11.

As set up for the shock-tube experiment, the delay computer's up-clock oscillator (f_l source) was an on-board crystal controlled module (M1 in the schematic) operating at 10.000 ± 0.0001 MHz. The down-clock signal (f_2 source) came from an external function generator configured to produce TTL 50% duty cycle square waves within a frequency range of 0 to 5 MHz. Switches S1 and S2 permitted "dry cycling" the entire system to verify all functions.

Summary and Conclusions

The time delay computer's delayed output signal was used to fire an air gap spark lamp which was the Schlieren camera light source in the shock-tube experiment. Event timing was obtained by feeding the computer's start and stop trigger impulse outputs (from IC1 and IC2) to a pair of digital timers. The digital timers provided a means of verifying that the system had functioned properly even before the photographs were processed. A third digital counter/timer was connected to the down-clock oscillator so that its frequency could be set before each shock-tube experiment.

The digital time delay computer proved invaluable in the shock-tube experiment for which it was designed. Once the device's capabilities were developed, it proved possible to use large format photographic negative film requiring hours or days to produce a viewable picture with great confidence that the desired results would be obtained. These large negatives yielded a degree of detail and clarity not obtainable in any other way. The event positioning accuracy in the shock-tube experiment was limited by the input and output devices and not by the time delay computer itself. However, it is important to note that the time delay computer produced extremely consistent results.

There are many other potential applications for the digital time delay computer. In the field of aeroballistic testing, for example, free-flight photographs of new gun/projectile/propellant combinations are often desired when available hardware and testing time are limited. Accurate pretest estimates of projectile velocity and velocity decay are difficult until a body of experience with the combination has been accumulated. Use of a digital time delay computer in conjunction with the standard photographic and x-ray equipment could greatly expedite testing by ensuring that the required data is obtained from every shot despite variations from the expected performance.

Reference

[1]Weber, P.A., "Shock Induced Starting of Gasdynamic Laser Nozzles," Air Force Institute of Technology, AFIT/GAE/AE/79D-17, Dec. 1979.