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FAST RISE-TIME PRESSURE-GAGE
CALIBRATOR

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Ballistics Research Report 86

FAST RISE-TIME PRESSURE-GAGE CALIBRATOR

Prepared by:

R. H. Waser and V. C. D. Dawson

ABSTRACT: This report describes a pressure-gage calibration device which simulates both the magnitude and the rise-time characteristics of pressure pulses experienced in shocktubes and shocktube wind tunnels. The advantage of a device of this type over a static calibration device is that it provides the ability to detect any difference in the static and dynamic characteristics of gages. Included is also a discussion of the response of gages to pressures with short rise times.

PUBLISHED MARCH 1963

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

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UNCLASSIFIED

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FAST RISE-TIME PRESSURE-GAGE CALIBRATOR

This work was sponsored by the Re-Entry Body Section of the Special Projects Office, Bureau of Naval Weapons, under the Applied Research Program in Aeroballistics.

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Captain, USN
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By direction

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REFERENCES

- (1) Timoshenko, S., Vibration Problems in Engineering, D. Van Nostrand Co., Inc., Princeton, N. J., 1955
- (2) Frankland, J. M., Effects of Impact on Simple Elastic Structures, DTMB Report 481, Apr 1942
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INTRODUCTION

The design and use of pressure transducers are frequently complicated by the need to measure extremely transient pressures accurately. In shocktube wind tunnel development, for example, one is faced with the problem of measuring shock pressures which rise to peak value in the time required for the passage of a fast-moving shock front. Thus, the gages are often subjected to pressure fluctuations that occur in a matter of microseconds.

Generally the gage designer employs a static calibrating system in order to determine the sensitivity and calibration curve of the transducer. This calibration is then applied in determining the results for the case where the gage undergoes truly dynamic loading. As will be shown in the next section, the applicability of the static calibration to the dynamic reading is a question of the frequency response of the transducer. Beyond this, however, is the question of what dynamic conditions do to the gage. Since the pressure application is to be fast, will the gage have dynamic characteristics that are not apparent under static conditions?

To eliminate this question many people have, in the past, attempted to design and develop dynamic calibrating systems. This report describes one of several systems that was developed for use in calibrating low-pressure (0 - 100 psi) transducers.

CALCULATIONS

Most pressure transducers rely on the relative movement of one part of the system with respect to another part; this motion being used to develop a signal (such as strain in a deflected diaphragm or charge on a crystal stack) which can be measured. The magnitude of the motion is generally related to the sensitivity while the time with which the motion takes place is related to the frequency response. This latter quantity should be high when the gage is used to measure rapidly varying pressures.

A transducer system can usually be considered as a vibrating structure which is subjected to a force application varying with time. Generally the structure has many modes or frequencies of vibration. For simplification, however, this complex structure can be replaced by a simple spring-mass system having a single vibration frequency (which is normally considered to be the fundamental of the actual gage system) (refs. (1) and (2)).

Several important conclusions on gage performance can be made by analyzing the spring-mass system. If, for example, a step function is applied to the spring mass shown in figure 1(a), the deflection at any given time is

$$\begin{aligned} X &= \frac{F_0}{k} (1 - \cos \omega_n t) \\ &= X_{st} (1 - \cos \omega_n t) \end{aligned} \quad (1)$$

This shows that the deflection under the application of a step force function varies harmonically from 0 to 2 times the static deflection. This oscillation occurs at the natural frequency as shown in figure 1(b).

If the force pulse applied is as shown in figure 2(a), i.e., the force rises linearly in time τ from 0 to F_0 , then the maximum amplitude the mass has depends upon the ratio τ/τ_n as shown in figure 2(b). If $\tau = 0$ the maximum amplitude is twice the static value and for $\tau > 0$ the maximum amplitude decreases until for very large values of τ the value of X_{max}/X_{st} is equal to 1. It is to be noted that if $\tau/\tau_n < 1$ the largest amplitudes occur. This fact then provides us with a logical definition for a dynamic load. Such a load occurs when the time of load application is less than the natural period because under this condition deflections in excess of 1 and up to 2 can occur. Such a pressure application to a transducer will cause ringing of the gage.

The gages in use at the Naval Ordnance Laboratory (ref. (3)) have a resonant frequency of 33 to 60 KC (resonant period of 30 to 17 μsec). Thus, to have a dynamic pressure pulse, the time of application should be less than these values. Various systems have been tried at the Naval Ordnance Laboratory in order to provide a dynamic pressure pulse. All of these involved the use of a large reservoir of gas which vented by means of a rupturable diaphragm or poppet valve into a small cavity which contained the transducer. By using a cavity, infinitesimal compared to the large cavity, the initial pressure before valve opening represents the final pressure that the gage feels.

None of the designs that evolved using pressure application and quick-opening valves were successful in calibrating the NOL gages dynamically. The best rise time that was obtained was about 125 μsec .

If one re-examines the spring-mass system in more detail, several conclusions can be reached which simplify the development of a dynamic calibrator. For the system in figure 1(a), the equation of motion is

$$m\ddot{x} + kx = F(t) = F_0 \quad (2)$$

However, if we take the same system without a forcing function but with an initial deflection X_0 , then we have

$$\begin{aligned} m\ddot{x} + kx &= 0 \\ t=0: \quad x &= X_0, \quad \dot{x} = 0 \end{aligned} \quad (3)$$

For this case if we let $y = X_0 - x$ and then substitute in equation (3) for $\ddot{x}$ and x , we have

$$\begin{aligned} m\ddot{y} + ky &= kX_0 = F_0 \\ \text{if } F_0 &= kX_0. \end{aligned}$$

Thus, the system described by equation (3) in terms of the y coordinate is completely equivalent to equation (2) within an additive constant. This means that if we apply a pressure to a gage and then rapidly release it, the system will react exactly as if the pressure were suddenly applied to the static gage.

DESIGN AND OPERATION OF CALIBRATOR

Figure 3 is a sketch of the calibrating block that was designed and built. With the transducer in place, the end of the cavity is sealed with a cellulose acetate diaphragm. The cavity is then pressurized with oil to the desired value, air being bled out through the capillary connection. The diaphragm is ruptured by a needle causing the pressure to release. Oscilloscope triggering is obtained by using the internal triggering feature of the oscilloscope.

Oil is used as the fluid medium since it has a very low compressibility. Thus, very small increases in volume cause a rapid pressure decrease and the complicated wave-action effect that is usual with a compressible fluid is minimized.

TEST RESULTS AND DISCUSSION

Figure 4 is the trace obtained with a pressure gage such as shown in figure 5 when a pressure of 60 psi is released

by the diaphragm. The trace shows considerable ringing indicating the pulse was released at a time considerably less than the natural period of the gage. Based upon the amount of overshoot of the trace ($X_{max}/X_{st} \approx 1.7$) and the natural period of the gage (from the trace this is about 30 μ sec) the release time for the pulse can be calculated. For the case above the release time is about 13 μ sec. Thus, the oil calibrator system does provide a usable method of subjecting a transducer system to a step pulse with a rise time of about 13 μ sec.

One very interesting result was obtained with the strain-gage type transducers. It was found that the mean pressure, as read from the pressure traces, continued to rise to a value about 6 percent higher than the initial value in a period of about 200 to 300 milliseconds. A similar but somewhat smaller result has been noted with other calibrating systems having slower rise time. The authors believe that this effect is caused by the beam material and bonding cement used to mount the gages on the beam, i.e., they are viscoelastic in nature. Until further definitive work is performed, users of calibration devices having fairly fast-acting pressure pulses should investigate not only the initial rise but also the long time (several seconds) pressure value to determine if the effect mentioned is present in their gage and calibration system.

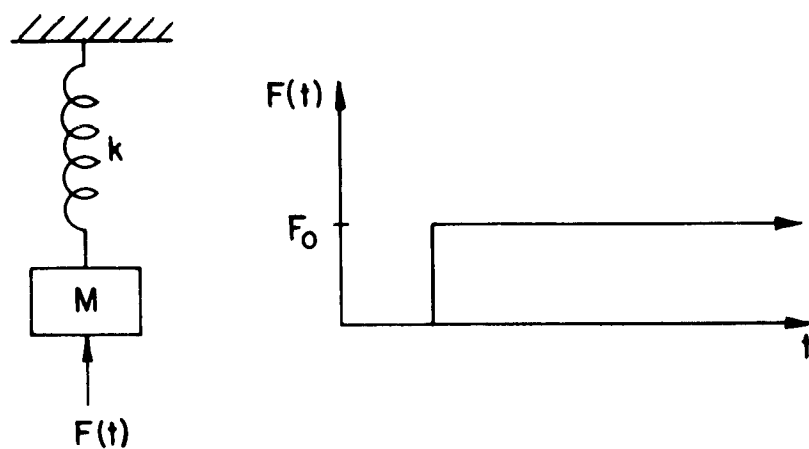


FIG. 1a SPRING-MASS SYSTEM AND APPLIED PULSE.

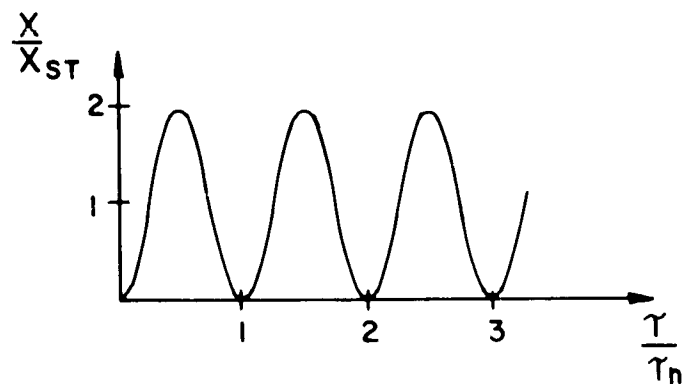


FIG. 1b RESPONSE OF SPRING-MASS SYSTEM.

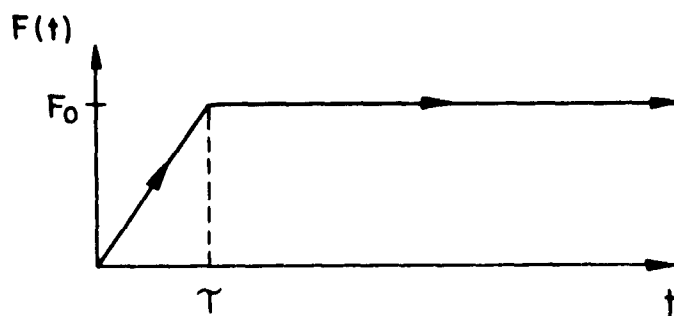


FIG. 2a APPLIED PULSE

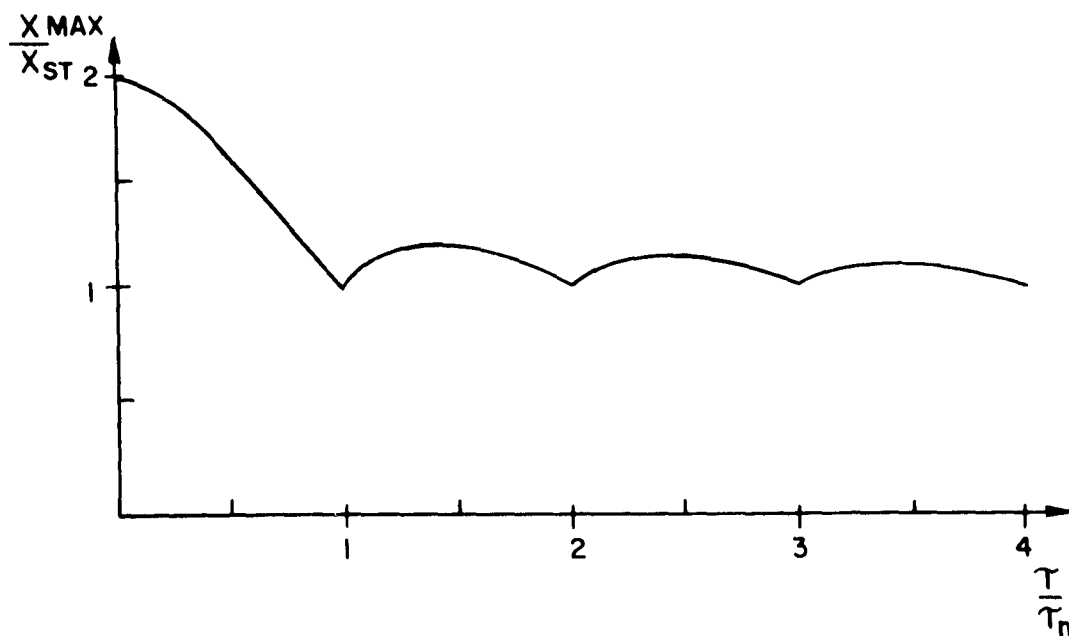


FIG. 2b RESPONSE OF SPRING MASS SYSTEM

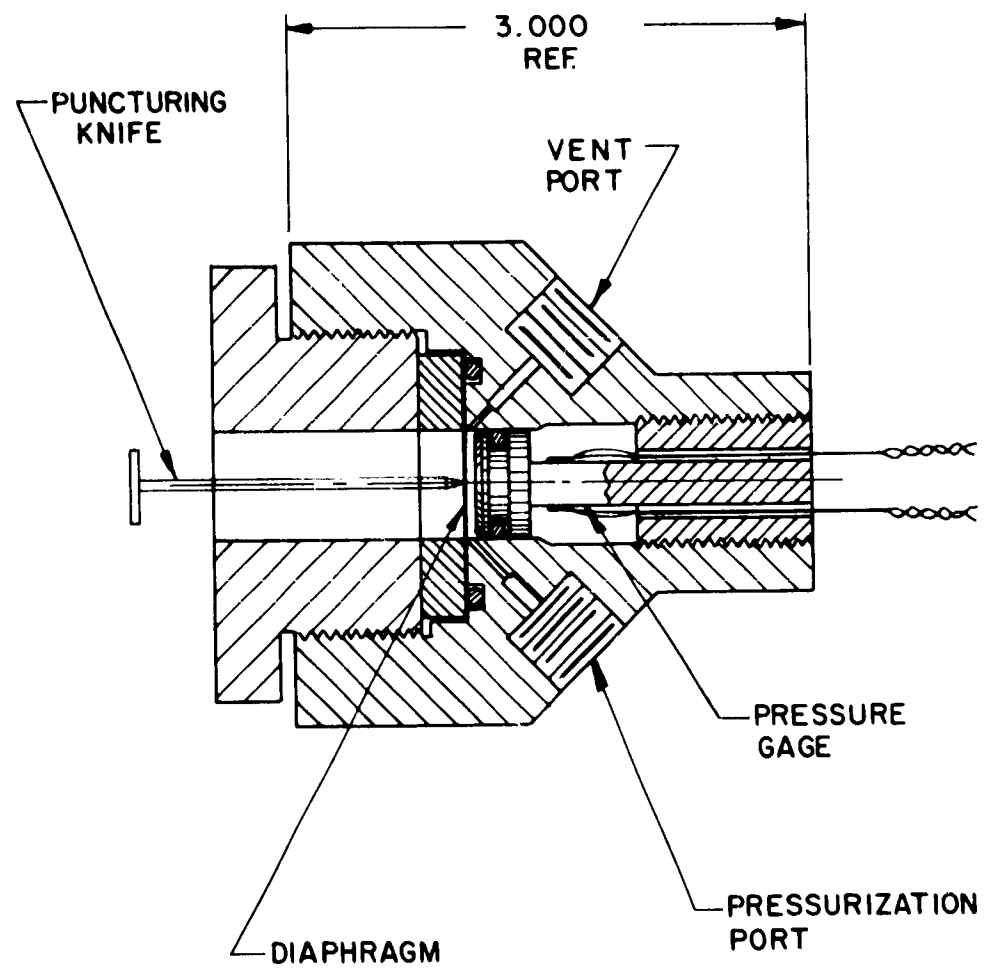


FIG. 3 CALIBRATING BLOCK

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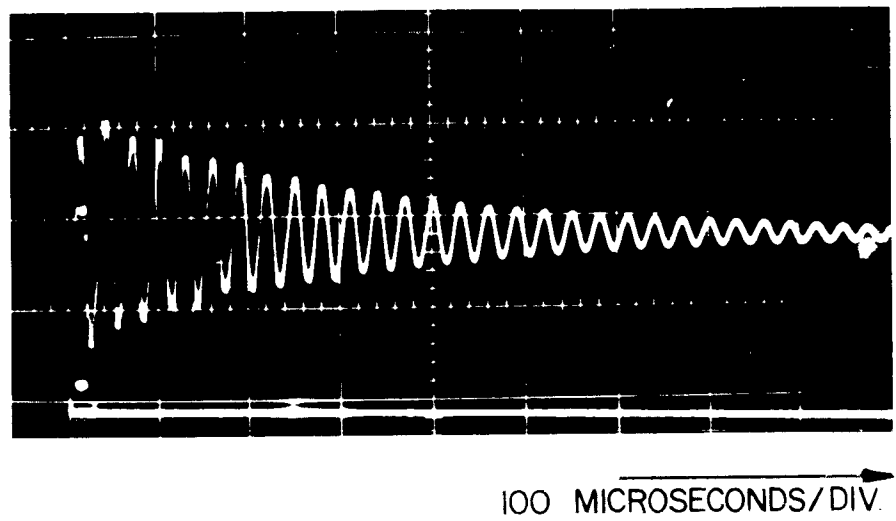


FIG. 4 PRESSURE GAGE CALIBRATION TRACE

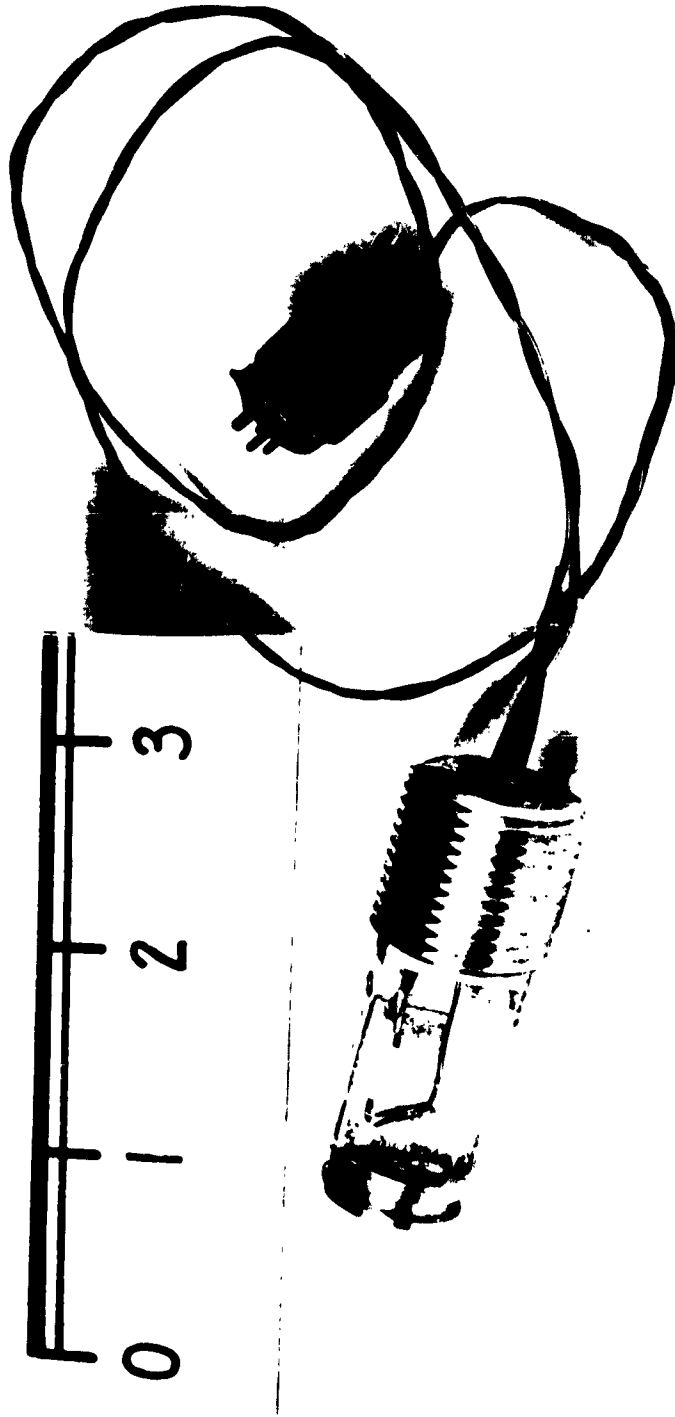


FIG. 5 PRESSURE GAGE

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Fast	FAST	Calibrator (Design)	CALRD
Rise	RISE	Calibrator (Operation)	CALRI
Time	TIME		
Calibration	CALB		
Device	DEVI		
Simulation	SIMU		
Pulses	PULS		
Shocktubes	SHTU		
Wind-tunnels	WINU		

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