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A Constant Current Source for Manganin Gauge Transducers*

DENNIS E. GRADY
Physics Department, Washington State University, Pullman, Washington 99163

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The piezoresistive property of manganin has previously been exploited in producing a pressure gauge for shock wave studies. This article describes a constant current supply for the manganin gauge that utilizes an inductor as the essential constant current component. It is shown that the assumption of constant current can be made with negligible error. A termination technique is described which eliminates the gauge shunting current and hence simplifies data reduction.

INTRODUCTION

THE dynamic properties of solids under shock conditions produced by impact techniques are presently an active region for both experimental and theoretical research. It is imperative that reliable experimental apparatus be available for obtaining usable data. An established technique for measuring stress–time profiles in the submicrosecond realm is the manganin gauge. Manganin has the virtue of a linear coefficient of resistance up to approximately 170 kilobars.[1] In conjunction with a source of constant current this gauge can be used to yield voltage–time oscilloscope records which are reducible to stress–time data.

This article describes a constant current supply that utilizes a large inductor as the essential component. A current is maintained in the inductor via an alternate path. Microseconds before the arrival of the stress wave the current is rerouted through the gauge. The current is maintained constant within negligible error by the large inertia of the electromagnetic field enveloping the inductor. This is considered quantitatively in Appendix A.

This supply has also been found to be quite convenient during the preliminary setup of the system. The initial voltage step produced when the current is rerouted through the gauge is reliably consistent when the supply is pulsed a number of times. Knowledge of the magnitude of this step is necessary for an analysis of the results. We have found it possible to make this measurement prior to the shot.

An alternate method for terminating the signal cable has been incorporated into the present scheme. By an appropriate choice of resistance values the signal cable can be terminated at the gauge end. This technique eliminates the dc shunting current at the gauge and hence eliminates an unnecessary complicating factor in the reduction of data. The validity of this method is discussed in Appendix B.

OPERATION

The essential operating characteristics can be seen with the aid of the block diagram in Fig. 1. Briefly, in the standby state a transistor gate is held open maintaining a current in the inductor. Prior to arrival of the stress wave at the gauge the supply is triggered externally. The electronic switch opens a silicon control rectifier (SCR) and closes the transistor gate rerouting the current through the gauge.

A schematic of a working constant current supply is shown in Fig. 2. Normal operating voltage and current are 50 V and 0.5 A. This is supplied by a stable (less than 0.1% fluctuation) floating voltage source.

The constant current supply completes an operational cycle in the following manner. Upon closing switch S1, the potential across SC1 comes to 50 V. This turns on transistors T2 and T1, respectively. In this standby state current follows the path from the supply through inductor I1, transistor T1, and then returns. The base current for transistor T2 which must transit the gauge is less than 1 mA and hence constitutes no heating danger to the gauge. To switch the supply to the active state, inject a positive pulse at the trigger input. This trips SC2, discharging capacitor C1 across transformer TF1. This ramp pulse is coupled through TF1 and trips SC1. The potential across SC1 drops to zero. This turns off transistors T2 and T1. The current is then rerouted through the gauge and SC1. The turnon time is less than 3 μsec. The inductor then maintains a constant current through the gauge for the required recording time, which is generally less than 10 μsec. After approximately 50 μsec the variable

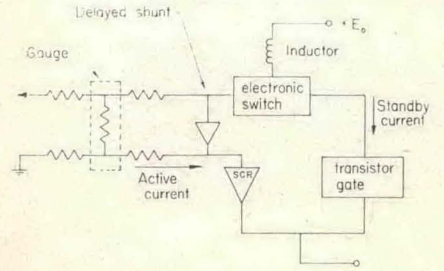

FIG. 1. Simplified block diagram.

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[1] D. D. Keough, "Procedure for Fabrication and Operation of Manganin Shock Pressure Gauges," Stanford Research Institute Tech. Rep. AFWL-TR-68-57 (August 1968).

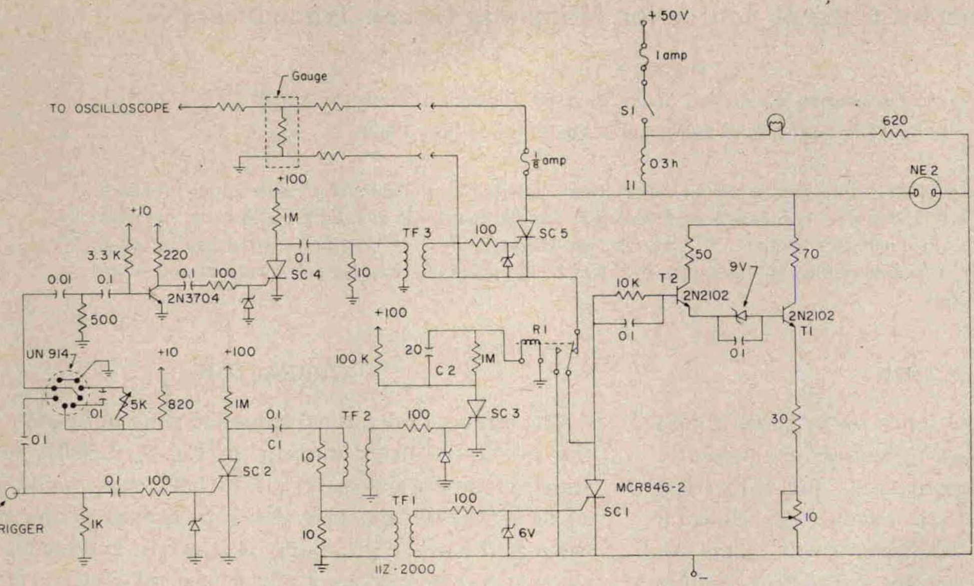

FIG. 2. Schematic of manganin gauge constant current supply.

delay consisting of the UN914 trips SC4. The pulse is coupled through transformer TF3 which, in turn, trips SC5. The opening of SC5 relieves the gauge of the current. This protects the gauge element from overheating while pulsing the supply during preliminary setup. Previously when SC2 tripped, the pulse was also coupled through transformer TF2 and tripped SC3. The discharge of capacitor C2 through the coil of relay R1 eventually mechanically breaks the current circuit and allows SC1 and SC5 to reset. The time required for this to occur is approximately 2 msec. The high back emf inevitably produced by inductor I1 when the circuit is broken is limited by the ignition of the neon bulb across the circuit. The supply has now completed a full cycle and has returned to the standby state. Figure 3 shows the voltage step developed across a 3 Ω gauge during one cycle of the supply. Also shown in Fig. 3 is a voltage–time record obtained with this system. The profile is a 38 kilobar final state shock wave in 6061-T6 aluminum.

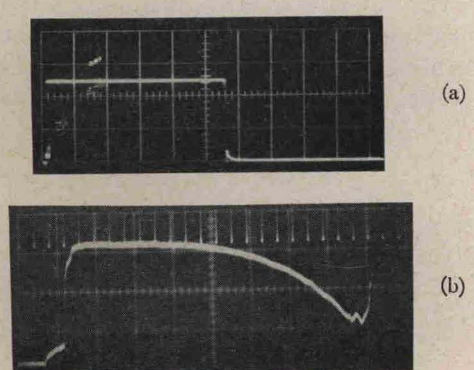

FIG. 3. (a) The oscillograph is of a voltage developed across a 3 Ω gauge during a cycle of the supply. The scale is 10 μsec/div. (b) Voltage–time record of a 38 kilobar final state shock wave in 6061-T6 aluminum. The scale is 0.5 μsec/div.

DISCUSSION

The ability to calculate pressure magnitudes follows from knowledge of the pressure coefficient of resistance,

$$(1/R)(\Delta R/\Delta P)=\text{const.}$$

If we use the gauge in conjunction with a constant current supply Ohm's law becomes

$$\Delta V=I\Delta R.$$

We thus obtain the relation

$$(1/V)(\Delta V/\Delta P)=\text{const},$$

which is in terms of the pressure change and immediately measurable quantities. This simple relation is not directly applicable unless several perturbing factors are controlled. The first is that the current must be maintained constant within some tolerable limits. The other is the complication introduced by the shunt current produced by terminating the signal cable at the oscilloscope. In the present scheme the first factor is eliminated by utilizing the property of an inductor to maintain constant current. The second factor is eliminated by incorporating the alternate terminating technique.

This supply has also been found to be very reliable in setting up the recording oscilloscopes to the very sensitive offset vertical voltage levels needed to observe the stress profile to the desired degree of resolution.

APPENDIX A

The assumption is that the inductor maintains a constant current independent of any change in resistance of the gauge. In actuality, if the gauge does change resistance, the current will begin to change dependent on some L/R

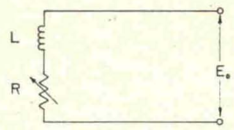

FIG. 4. Equivalent circuit of current supply when current path is through the inductor and gauge plus terminating resistors.

time constant. We will show that the error produced by this is negligible. The equivalent circuit is shown in Fig. 4 where E_0 is a constant voltage source, L is an inductance, and R is the gauge plus terminating resistors. At some time, $t=0$, the value R will change from R to $R+\Delta R$ representing the change in resistance due to the arrival of a stress wave. Solving the differential equation

$$L dI/dt+I(R+\Delta R)=E_0$$

with the initial conditions

$$I(0)=E_0/R=I_0$$

gives the exact solution

$$I(t)=\left(\frac{E_0}{R}-\frac{E_0}{R+\Delta R}\right)e^{-(R+\Delta R)t/L}+\frac{E_0}{R+\Delta R}.$$

Assuming small time and assuming ΔR is small compared to R give the approximate current dependence on time,

$$I(t)\approx I_0(1-\Delta Rt/L).$$

The incremental change in voltage due to the resistance change is

$$\Delta V(t)\approx I_0(1-\Delta Rt/L)\Delta R.$$

The assumption of constant current implies the relation

$$\Delta V=I_0\Delta R.$$

Therefore the error in this assumption is

$$e=[I_0t(\Delta R)^2]/L.$$

In practice the initial current is 0.5 A, the recording time is less than 10 μsec, the inductance is 0.3 H, and R is 100 Ω. A maximum for the change in resistance is 3 Ω. This yields an error on the order of 0.01%.

APPENDIX B

When transmission of high frequency information on coaxial cable is necessary, it is imperative that proper termination procedures are followed. The signal cable may be termined at the oscilloscope, but this produces a shunting current that complicates the reduction of data. Figure 5(a) shows the actual manganin gauge circuit with representative values for the gauge and terminating resistors. Figure 5(b) shows the equivalent circuit. The gauge is represented by a voltage source while the gauge resistance and termination resistance are lumped into the value R.

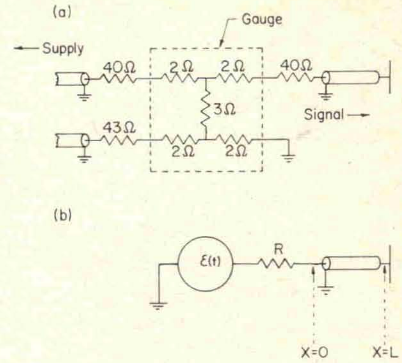

FIG. 5. Manganin gauge circuit. (a) The actual circuit including representative gauge and terminating resistor values. (b) The equivalent circuit.

The validity of this termination technique can be seen from the following derivation.[2] In a lossless transmission line, both voltage and current satisfy the wave equation

$$\partial^2 I/\partial x^2-LC\partial^2 I/\partial t^2=0$$

$$\partial^2 V/\partial x^2-LC\partial^2 V/\partial t^2=0,$$

with the boundary conditions

$$I(L)=0$$

and

$$V(0)+I(0)R=\mathcal{E}(t).$$

If we adjust the gauge resistance and terminating resistor such that R is equal to the characteristic impedance of the cable, Z, the boundary conditions become

$$I(L)=0$$

and

$$V(0)+I(0)Z=\mathcal{E}(t).$$

The general solution for current and voltage is

$$I=f(x-ct)+g(x+ct)$$

and

$$V=Z[f(x-ct)-g(x+ct)]. \tag{1}$$

The boundary conditions give

$$f(L-ct)+g(L+ct)=0 \tag{2}$$

and

$$2f(-ct)=\mathcal{E}(t)/Z. \tag{3}$$

Since these conditions must hold for any argument in the domain of the solution, we have from Eq. (3)

$$f(L-ct)=\mathcal{E}(t-L/c)/2Z \tag{4}$$

and from Eq. (2)

$$f(L-ct)=-g(L+ct). \tag{5}$$

We are concerned with the voltage at the oscilloscope. Using Eqs. (4) and (5) in Eq. (1) gives

$$V(L,t)=\mathcal{E}(t-L/c).$$

[2] The author is indebted to Dr. G. E. Duvall and D. Andrews for suggesting this approach.

Thus, the voltage recorded at the oscilloscope is the voltage produced by the gauge but delayed by the transit time of the cable.

In other words, the voltage at the gauge initially sees a voltage divider consisting of the input resistance and cable impedance. It therefore transits the cable at one-half the gauge voltage. Upon arriving at the oscilloscope the pulse sees an open circuit and thus doubles its voltage propagating back along the cable as a reflected wave. The reflected wave upon reaching the gauge is properly terminated. In practice there is a problem in that R does not maintain a constant value during the transit of the stress profile. It has been found that if the resistance is chosen such that proper termination is effected when the gauge reaches its final state value this problem is eliminated.

ACKNOWLEDGMENTS

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