Technical note

A stable ultraminiature catheter-tip pressure transducer*

Keywords—*Pressure transducer, cardiac catheter, strain gauge, haemodynamics*

Introduction

THE DYNAMIC-response problems associated with liquid-filled catheters connected to external pressure transducers for cardiovascular studies are well known. Relief from these problems has been sought through various forms of catheter-tip transducers, the most promising of which have been those utilising semiconductor strain gauges. The primary drawbacks of the semiconductor units have been their fragility, limited life and their lack of resistance stability, which precluded long-term *in vivo* calibration. Recently, in response to needs in this laboratory for the continuous recording of the aortic-pressure pulse wave for the assessment of cardiac output, a semiconductor-strain-gauge catheter-tip pressure transducer has been developed which overcomes these problems. The transducer has such high sensitivity that, connected into a simple d.c. bridge circuit, it can provide stable high-level output without the use of a carrier amplifier. In addition, the transducer is temperature-stable and insensitive to flow.

Physical features of the transducer

Fig. 1 shows the transducer, which is 12 mm long and has a diameter of 1·65 mm. It is mounted at the tip of a no. 5 French Teflon (polytetrafluorethylene) catheter, 1·5 m long. On the other end of the catheter is an electrical connector for connecting the transducer to a source of excitation and a signal conditioner. A hole in the connector provides an opening to the atmosphere for the rear of the diaphragm.

The active portion of the transducer consists of a silicone-rubber diaphragm with an effective area of 0·75 mm^2. Pressure applied to the diaphragm is transmitted by a linkage to two silicon strain gauges. The gauges are secured at both ends so that the stressed portions are in air and not bonded to any surface. On application of pressure, one gauge is stretched, and the other is compressed. This arrangement increases the sensitivity over that possible from a single gauge and provides temperature compensation.

In addition to pressure measurements within vessels which can accommodate the catheter, external measurement through very small catheters are possible by use of a special plastics dome having either a male or female Luer fitting. Each dome contains a small pressure-relief port which limits internal pressure to 1 mmHg, thereby preventing damage to the pressure sensor from accidental overpressurisation. Placement of a pressure transducer in a plastics dome is shown in Fig. 2.

Specifications

Some of the important electrical mechanical and thermal specifications for the transducer include the following:

(1) pressure range: ±300 mmHg
(2) overpressure: 1500 mmHg
(3) excitation: 1–10 V a.c. or d.c.
(4) nominal output: 0·1 V per 300 mmHg for 3·5 V excitation
(5) volume displacement: 2×10^{-3} mm^3 per 100 mmHg
(6) natural frequency: 15 kHz
(7) thermal stability: ±0·15 mmHg/°C over an ambient temperature range of 25–40°C
(8) Linearity and hysteresis: within ±0·5% of full scale over a pressure range of 0–300 mmHg

Transducer-control unit

Although the transducer will function with any standard carrier or d.c. bridge amplifier, the high output of the transducer (0·1 V per 300 mmHg) permits the direct drive of most d.c. recorders or oscilloscopes. A simple control unit has been designed to optimise this characteristic of the transducer and to provide for zero suppression and calibration of the transducer at any time without having to remove it from the vessel. The control unit supplies the excitation voltage to the

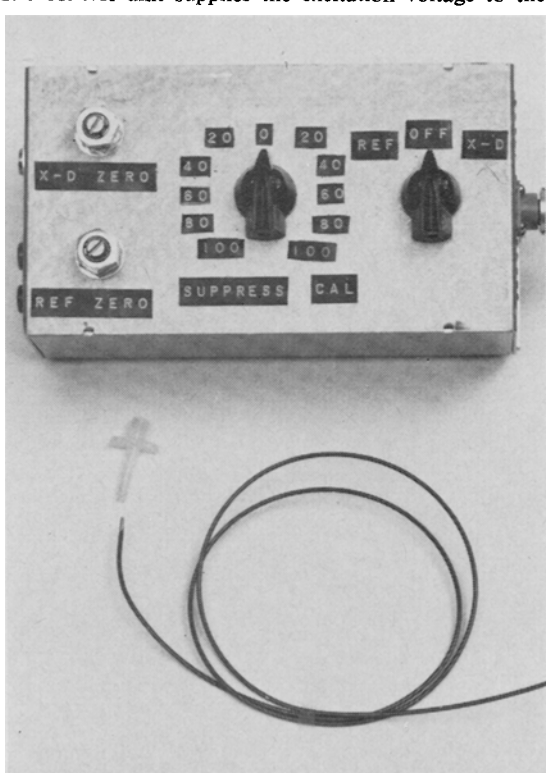

Fig. 1 The catheter-tip pressure transducer and control unit

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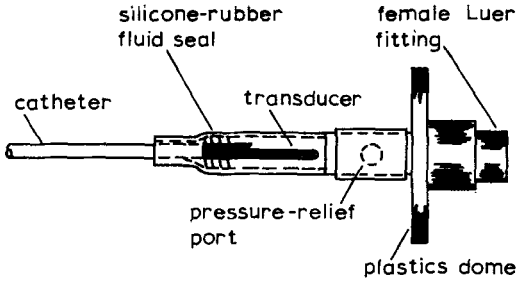
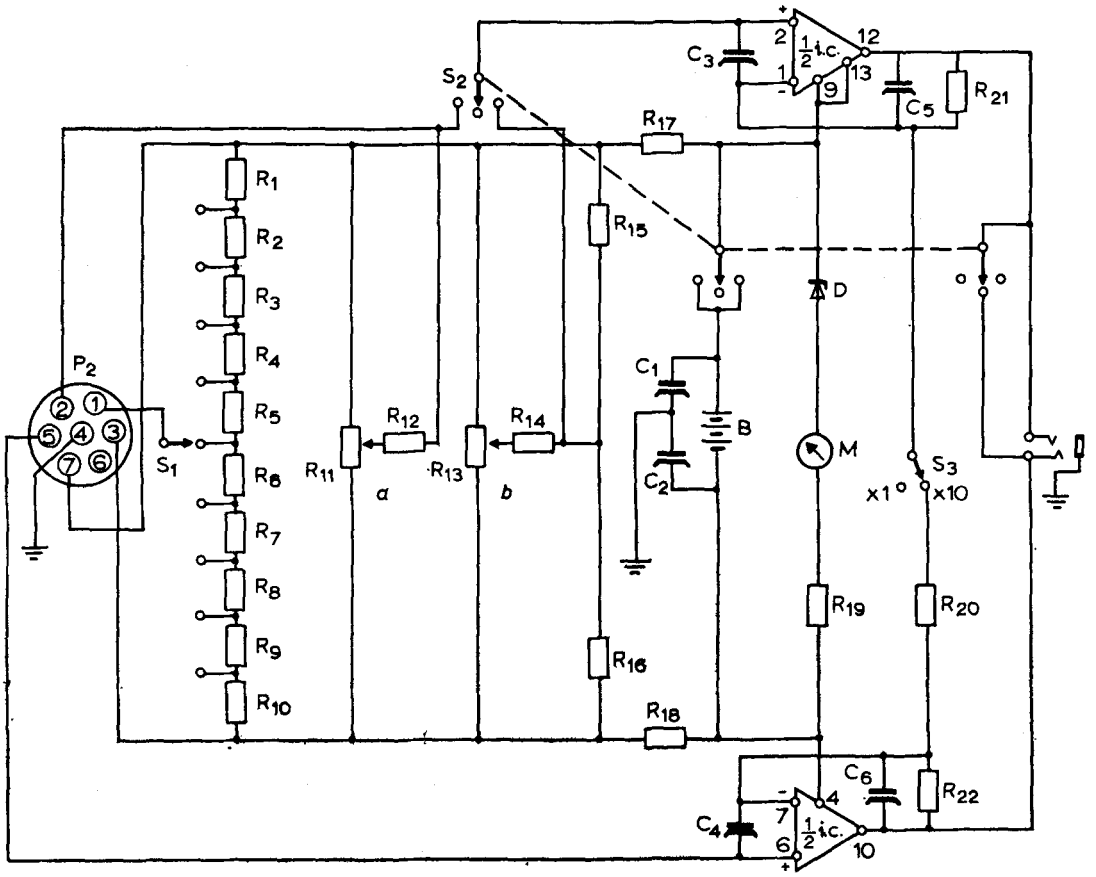


Fig. 2 The catheter-tip pressure transducer mounted in a plastic dome for making measurements through very small diameter catheters

transducer and the associated bridge circuitry. It also contains balance, calibration and zero-suppression controls.

A fundamental requirement for recording with a catheter-tip pressure transducer is that means must be provided for checking zero and for calibrating with the catheter tip in place. The outstanding long-term physical stability and thermal stability of the transducer (±0·15 mmHg per degC from 25 to 40°C) make reliable the reference to a simulated zero pressure by substitution of a reference half bridge for the strain-gauge half bridge in the transducer. Thus, with the transducer exposed to atmospheric pressure, the transducer bridge circuit and the reference bridge circuit are initially set to zero. Thereafter, the reference bridge may be used as a reference for zero pressure and for calibration during recording without removing the catheter from the subject.



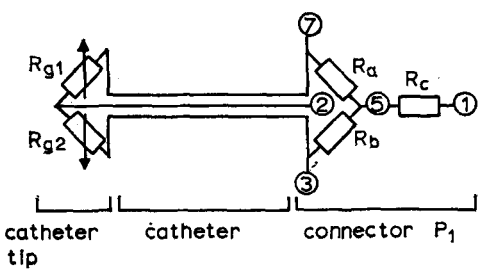


Fig. 3 Circuit diagram of pressure transducer and control unit.
a *Transducer zero* b *Reference zero*

Typically, stability within 1 or 2 mmHg has been obtained in experiments lasting up to 8 h.

Circuit information

Schematic diagrams of the transducer and control unit are shown in Fig. 3. The two active semiconductor strain-gauge elements (R_{g1}, R_{g2}) constituting one-half of a temperature-compensated bridge are located in the catheter tip. The remaining half of the bridge consists of resistors R_a and R_b and, together with the calibrating resistor R_c, is mounted inside the connector at the end of the catheter. The catheter, while providing a pressure reference vent to the atmosphere, also contains four wires. Three of these wires are connected to the active strain-gauge elements, while the fourth merely provides capacitive symmetry for the two wires connected to the amplifier input terminals. The calibrating resistor R_c is selected so that, when it is connected across one of the 1·5 kΩ fixed resistors R_a, R_b in the half bridge located inside the connector, the same voltage output is obtained as when a 100 mmHg pressure is applied to the two active strain gauges. In this manner, each catheter unit contains its own internal calibration.

The functioning of the system centres about the use of two bridge systems: a reference bridge and an 'active' bridge. The reference bridge consists fundamentally of the two half bridges formed by R_a, R_b and R_{15}, R_{16} while the 'active' bridge consists basically of the two silicon strain gauges R_{g1}, R_{g2} and the half bridge R_a, R_b. Thus the half bridge formed by R_a and R_b is common to both the reference and active bridges. Potentiometer R_{13} serves as the balance control for the reference bridge, and R_{11} for the active bridge. Switch S_2 selects the output from either the active or reference bridge for application to the bridge-amplifier integrated circuit. This integrated circuit is a single physical unit containing two amplifiers which are operated differentially in this application. The high output of the active bridge permits more than adequate output to drive most recording systems full scale with the amplifier operating at unity gain. However, if additional gain is desired, S_3 may be set to increase the amplifier gain to ten.

Capacitors C_1 to C_6 were necessary to eliminate interference from energy radiated from a nearby radio transmitter. The capacitors are not required when operating the unit in radio-frequency fields of normal intensity, but their use is recommended to ensure against the possibility of interference from r.f. sources.

Adjustments and calibration

Initial adjustments are begun with switch S_1 in the midposition (i.e. the junction between R_5 and R_6, and S_2 in the middle or off position. In the off position of S_2, the battery is disconnected and the output terminals short-circuited to provide a zero output voltage reference. With the catheter connected and exposed to atmospheric pressure, S_2 is operated to connect the reference half bridge into the circuit. The potentiometer R_{13} may then be adjusted to set the reference bridge to zero output voltage. S_2 is then operated to connect the 'active' semiconductor half bridge in place of the reference half bridge, and potentiometer R_{11} is adjusted to set the 'active' bridge to zero output voltage corresponding to zero or atmospheric pressure. After these adjustments have been made, the output voltage is zero for all three positions of S_2. With either the reference or 'active' bridge connected, S_1 may be operated to change the d.c. output voltage (baseline) in steps of 20 mmHg. Thus, when the reference bridge is connected, S_1 provides calibration steps of 20 mmHg either above or below zero (atmospheric) pressure. Similarly when the catheter is in a vessel and registering pressure changes, the baseline may be shifted in steps of 20 mmHg as desired. For example, if S_1 is operated to displace the pressure record downward by 40 mmHg, the initial zero output voltage level represents 40 mmHg on the pressure recording. Thus the zero level has been suppressed by 40 mmHg. Therefore, with this dual-bridge arrangement, the zero-pressure baseline is always known, and calibration may be done immediately at any time without removing the catheter from the vessel.

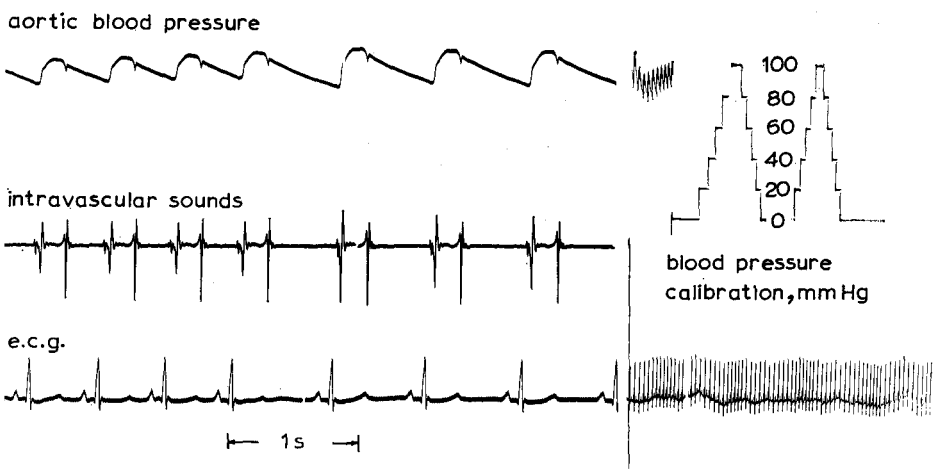


Fig. 4 Record of aortic blood pressure and intravascular sounds as recorded from the catheter-tip pressure transducer in the aorta of a dog

Safety

When used with the control unit, power to the transducer is supplied by four 1·35 V mercury cells. The present requirements are such that these cells should supply sufficient energy continuously for at least 500 h of operation before replacement is required. It is recommended that the cells be replaced annually even if 500 h has not been reached.

The use of very low direct voltage (5·4 V), together with complete isolation from the power mains and epoxy-resin insulation over the strain-gauge element within the tip, renders the device electrically safe. The current leakage from the transducer is less than 0·5 μA for an applied voltage of 150 V. Scaling this value linearly to the 5·4 V source would indicate a maximum possible source current leakage for the transducer of $21 \cdot 6 \times 10^{-9}$ A or 0·0216 μA. This is over two orders of magnitude below any a.c. level deemed dangerous for catheters placed directly within the heart chambers. D.C. excitation of the transducer increases the safety factor even further.

List of parts

The transducer, which requires special techniques for construction, is now available commercially.* However, the control unit is easily constructed from the components listed below:

R_{g1}, R_{g2}	silicon strain-gauge elements
R_a, R_b	1·5 kΩ
R_c	selected for particular transducer
R_1 to R_{10}	150 Ω
R_{11}, R_{13}	25 kΩ
R_{12}, R_{14}	100 kΩ
R_{15}, R_{16}	1·5 kΩ
R_{17}, R_{18}	150 Ω
R_{19}	500 Ω (nominal)
R_{20}	3·32 kΩ
R_{21}, R_{22}	15 kΩ
C_1 to C_6	0·001 μF
M	0–200 μA

B (four) RM12R 1·35 V mercury cells (Mallory)
Integrated circuit μA747 (Fairchild)
P_1 female connector 222-11N07 (Amphenol)
P_2 male connector 222-22N07 (Amphenol)

* Millar Instrument Co., Houston, Texas, USA

Intravascular sounds

Recently, the control unit has been modified to include a high-pass filter across the output terminals which permits the intravascular sound components of the blood-pressure pulse to be separated and amplified. Thus 'heart sounds' characteristic of specific locations within the vascular system may be recorded graphically and presented orally through an audio amplifier if desired. A record of blood pressure, intravascular sounds and e.c.g. recorded in the central aorta of a dog is shown in Fig. 4.

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