传感材料与传感技术丛书

Sensing Material and Sensing Technology Series

AUTOMOTIVE SENSORS

EDITED BY **JOHN TURNER**

影印版

汽车传感器

哈爾濱工業大學出版社
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影印版说明

《传感材料与传感技术丛书》中第一个影印系列 MOMENTUM PRESS 的 *Chemical Sensors:Fundamentals of Sensing Materials & Comprehensive Sensor Technologies*（6卷，影印为10册）2013年出版后，受到了专家学者的一致好评。

为了满足广大读者进一步的教学和科研需要，本次影印其 *Automotive Sensors*。

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PREFACE TO THE *SENSORS TECHNOLOGY SERIES*

The creation of the digital world is perhaps the most remarkable engineering event of the late twentieth century and may be compared in impact to the harnessing of steam at the beginning of the nineteenth. Obviously, the two cannot otherwise be compared, representing as they do the transition from the era of power to that of information. Even the term "transition" is misleading because the digital world depends entirely on the prior existence of sources of electrical energy, currently derived largely from thermal and nuclear processes, with an ever-increasing reliance on renewable content including the harnessing of tidal, wind and solar sources. Furthermore, chemical sources of energy should not be forgotten, including the wide range of "personal" batteries powering everything from laptop computers to hearing aids and pacemakers, and the currently-developing fuel-cell technology that may yet make the electric automobile a viable proposition.

The digital world is also dependent upon the provision of sources of information. Such input information can itself be digital, as when a human being types data directly into a computer or when nuclear disintegrations are counted by an appropriate sensor. However, other sources of information rely upon sensors that transduce phenomena derived from mechanical, optical or chemical/biological phenomena into (usually) electrical signals. Because real-world phenomena are predominantly analog in nature, these signals are therefore also in analog form. Such signals may then be amplified, conditioned and applied to analog-to-digital (A-D) converters for entry into the digital world—all major topics in their own right. Actually, there is always a level at which even digital processes take on analog characteristics. For example, the heat generated within computer chips arises mainly during the (analog) transitions between the ON and OFF states of the multitude of transistor structures contained therein.

The present series of volumes is entirely concerned with sensors themselves, and because the subject matter is so wide-ranging in both scope and maturity, this is reflected within the individual books. So, whereas care has been taken to include a considerable amount of practical material, the proportion of such leavening is inevitably variable. Thus, the volume concerning chemical sensors may be regarded as largely oriented towards research and development, whereas at the other end of the spectrum, the avionics volume and the present automotive volume are based largely on current practice. This disparity is in part driven by the safety-oriented conservatism in these latter fields, but future developments in both have not been ignored.

Though the gestation period of such a comprehensive series has been long, care has been taken to include information that is indeed both basic and also contemporary, so providing a platform for continued updating as progress continues.

The ever-increasing sensor/electronics content of a modern automobile is reflected in the proportion of the ultimate cost of the vehicle related to this content, and this is also true for equally-modern aircraft. In both cases the sensors currently employed in production models are well-tried, safe and reliable, and so command the bulk of the material presented here. The intention of both volumes is to provide the reader with an authoritative introduction to the theory, installation, and performance of these sensors prior to discussing future developments. An excessive use of theoretical or mathematical material has been avoided throughout, and it is hoped that this will lead to a unique "hands-on" approach.

The present volume begins with an overview of the sensor/electronic content of the modern automobile by the Volume Editor, Prof. John Turner, and each of the topics mentioned is then covered in greater detail in the succeeding chapters. All the authors are practicing automobile engineers currently working in industry or academia, and each chapter therefore represents an authoritative viewpoint gleaned from personal experience.

J. Watson
Editor-in-Chief
February 2009

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CHAPTER 1

Sensors in the Vehicle

John Turner

1. INTRODUCTION

Modern vehicles can have up to one hundred microcontroller-based electronic control units (ECUs). These are fitted to enhance safety, performance, and convenience. As the complexity and safety-critical nature of automotive control systems increases, more and more sensors are needed.

The problems of congestion and environmental effects associated with increasing vehicle ownership and use are well known. Throughout the world, the climate of opinion is turning against unfettered mobility. In most developed countries, government transport policy places increasing emphasis on the efficient management of existing roads and recognizes the difficulty of satisfying demand by building new roads. The use of a combination of information technology (IT) and electronic systems to advise drivers and reduce their workload is being seen as offering at least a partial solution to current and projected traffic problems, since it has been shown to smooth the traffic flow [1]. Advanced sensing and control systems also offer the possibility of safely reducing the gaps between vehicles (the "headway"), thus increasing the number of vehicles that can use a particular stretch of road.

The combination of IT and vehicle-based and highway-based electronic systems has become known as *automotive telematics*. All telematic systems rely heavily on sensors and measurement techniques, and this is especially true of those applications that are safety critical. Many research projects are currently underway in this area, which is particularly challenging for the sensor designer in the light of typical automotive cost constraints. (As a rule of thumb, at 2005 prices, a vehicle manufacturer will normally tolerate a "measurement cost" of only around $10 per measurand, including all the signal conditioning required). If an automotive sensor costs significantly more than this, the extra cost has to be justified in terms of additional functionality, perhaps because the measurement can be used for several purposes.

Highway sensor costs are much higher than those of automotive devices. There are two main reasons for this. First, the volumes are much lower—many highway sensors are almost custom made for a particular application, and volume production runs of any particular configuration are rare. Second, the cost of the associated groundwork has to be taken into consideration. These factors mean that the cost of installing, for example, a loop detector (explained in section 3.1) is typically several thousand dollars.

To succeed commercially, automotive sensors have to be very robust. They must tolerate an environment that includes temperatures from –40 to +140 °C, possible exposure to boiling water, battery acid, fuel, hydraulic fluid, road salt, and so forth, as well as very high shock and vibration loads, which can exceed 1000 g on the unsprung side of the vehicle suspension. They may also have to tolerate and function in the presence of high levels of electromagnetic noise.

Highway sensors also have to be robust. They too experience the full range of climate conditions, and may also occasionally be exposed to fluids originating from motor vehicles. In general, however, the shock and vibration environment is less demanding, and the cost constraints are usually less extreme.

2. ON-VEHICLE SENSORS

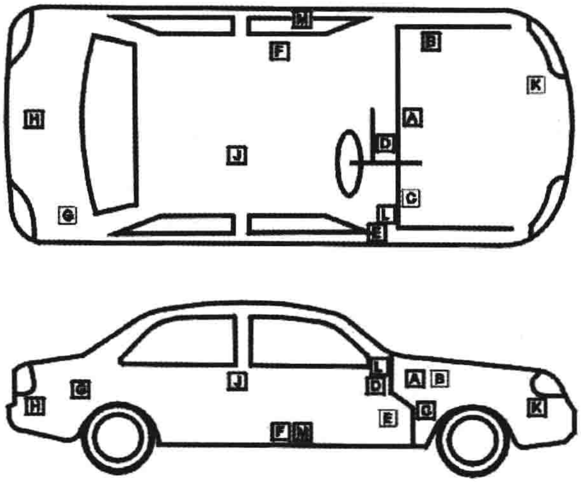
A good example of the trend towards increasing complexity is provided by the air bag system. Early (1980s) systems typically used an accelerometer and a "safing sensor" (to avoid inappropriate firing of the airbag, for example, when the vehicle is stationary). Current designs may include sensors for child seat detection, seat position, occupant position, occupant detection, and vehicle speed. Rollover sensors, side impact sensors, weight sensors, tire inflation sensors, and tire temperature sensors may also be used. Several sensors may be required to monitor different seats or zones within the vehicle.

A similar increase in sensing complexity has taken place in powertrain control systems, vehicle body controllers (e.g., door locks, windows, sunroofs, and wipers), and chassis control systems. This has produced significant benefits in system performance, but has also created some real challenges.

A complex electronic/electromechanical system, such as a modern motor vehicle, has to be operated in intimate varying interaction with its driver and with an outside world of considerable complexity. For any such system to operate satisfactorily, the need for effective, accurate, reliable, and low-cost sensors is very great. Electronic measurement systems can be applied very widely within a motor vehicle, as shown in figure 1.1. The complexity can range from the interactive control of engine and transmission to optimize economy, emissions, and performance to the simple sensing of water temperature and fuel level.

2.1. POWERTRAIN SENSORS

The complexity of the control task involved in powertrain management is demonstrated by figure 1.2. Table 1.1 lists typical required specifications for the powertrain sensors. The accuracy and temperature range over which these devices have to operate should be noted, and it also must be remembered that they have to be of minimal cost and high reliability. A typical automotive sensor has a design life of up to 10 years, and should require no initial setting up or maintenance within that time. A fully comprehensive powertrain control system would contain most of the devices listed in table 1.1, although the really critical devices are those which measure engine timing, inlet manifold mass airflow, manifold vacuum pressure, exhaust gas oxygen content, transmission control valve position, transmission input and output speed, and throttle and accelerator position.



KEY:

A: ENGINE MANAGEMENT SYSTEM: CONTROLS IGNITION, FUELLING, EXHAUST GAS RECIRCULATION
B: ANTILOCK/ANTISKID CONTROL
C: VEHICLE SECURITY
D: STEERING MOTION SENSOR
E: DOOR SENSORS
F: CLIMATE CONTROL SYSTEM
G: FUEL TANK SENSING
H: CRASH SENSOR
J: ELECTRONIC TRANSMISSION CONTROL
K: BULB OUTAGE & ICE ALERT SESORS
L: ELECTRONIC INSTRUMENT CLUSTER, TRAFFIC & ROAD INFORMATION SYSTEM
M: DATA AND POWER BUS (CAN BUS)

Figure 1.1. Automotive measurement systems

2.1.1. Ignition Control

The ignition timing sensors available at present normally use Hall effect [2] or other electromagnetic transducers to detect the movement of a magnet or metallic projection attached to the flywheel. The major inaccuracies in ignition timing arise from mechanical vibration and torsion in the geared drive to the distributor from the engine crankshaft. This problem is likely to be partially overcome in future vehicles, where the timing is taken directly from the crankshaft, although this then requires an additional sensor on the camshaft to determine the correct timing for each cylinder in the four-stroke cycle. Crankshaft sensing itself may suffer from windup errors due to the main engine torque and the influence of differing operating conditions in each cylinder.

The measurement of inlet manifold vacuum pressure was the first sensing requirement in early ignition control systems [3], and it continues to be a very important parameter. It provides a relatively good measurement of engine torque, since as the engine slows down under load the inlet manifold vacuum pressure moves closer to atmospheric pressure. This effect is accentuated by the driver (who is part of the control loop) pressing the accelerator and opening the throttle further.

It would be much better to measure the engine torque directly, if a reliable low-cost way to do this could be found. The search for a low-cost, noncontact method of torque measurement is currently the subject of a great deal of automotive research, as discussed in chapter 6.

The inferred measurement of load by sensing manifold vacuum has been used for controlling ignition advance from a very early stage in the development of the internal combustion engine. For many years the preferred approach was mechanical. The load-related control was achieved through the use of an aneroid vacuum capsule connected to the manifold. The varying vacuum altered the aneroid capsule shape, producing a force that physically rotated the distributor to alter the ignition advance angle. At the same time, a centrifugal weight system further controlled ignition advance angle according to the rotational speed of the engine.

In an ignition system with electronic control, these functions are taken over by a pressure transducer connected to the manifold, and a measurement of the engine rotational speed is obtained from a

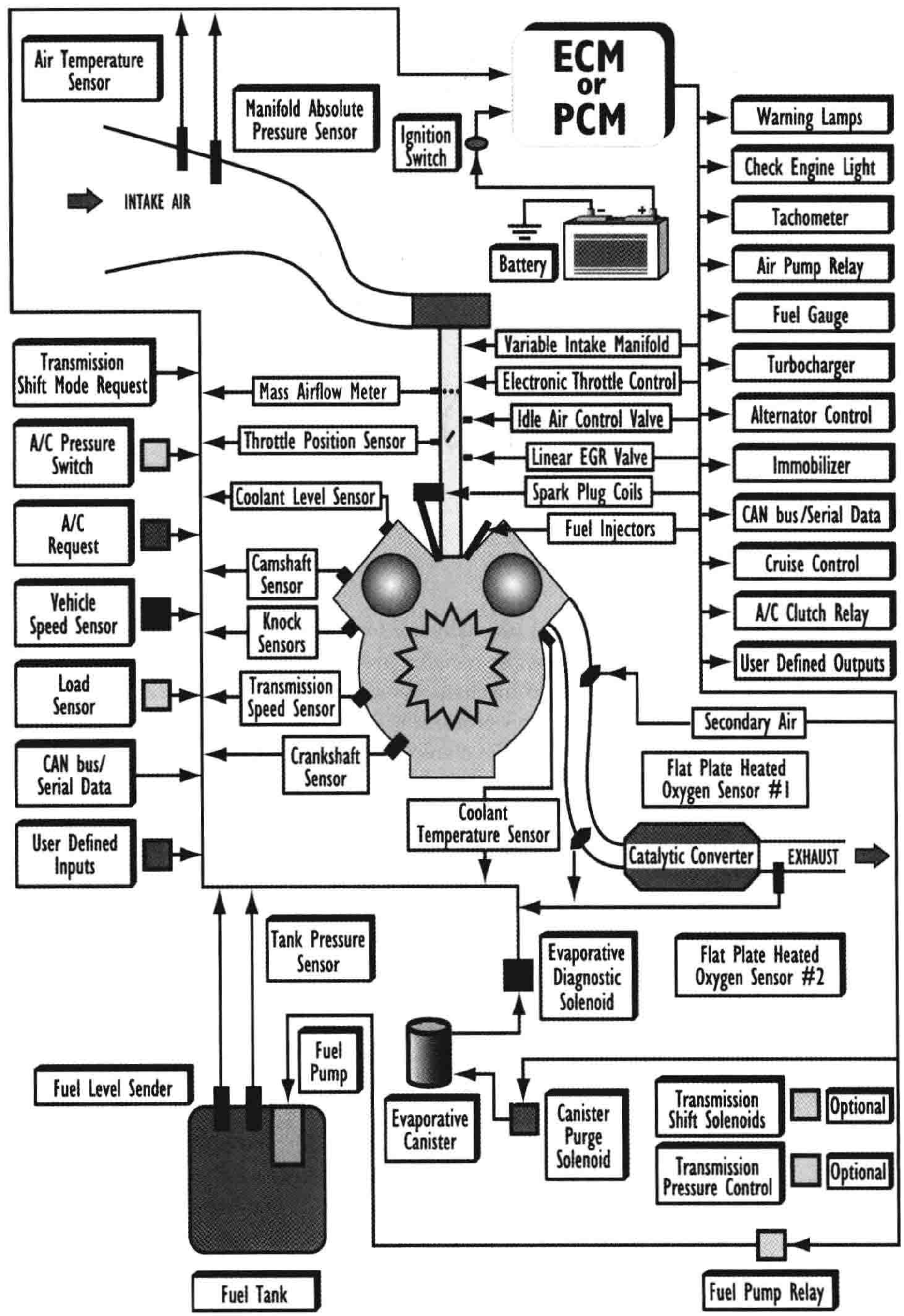


Figure 1.2. Typical powertrain management system

Table 1.1. List of powertrain sensor specifications, from reference 2

Sensor/type	Sensing method	Range	Accuracy (%)	Thermal range (°C)	Response time
Inlet manifold absolute or differential pressure sensor (gas engines)	Piezoresistive silicon strain gauged diaphragm *or* capacitive silicon diaphragm	0–105 kPa	±1 at 25 C	–40 to +125	1 ms
Inlet and exhaust manifold pressure sensor (diesel engines)	As above	20–200 kPa	±3	As above	10 ms
Barometric absolute pressure sensor	As above	50–105 kPa	±3	As above	10 ms
Transmission oil pressure sensor	Differential transformer and diaphragm, *or* capacitive diaphragm (often stainless steel)	0–2000 kPa	±1	–40 to +160	10 ms
Inlet manifold air temperature sensor	Metal film or semiconductor film	–40 °C to +150 °C	±2 to ±5	–40 to +150	20 ms
Coolant temperature sensor	Thermistor	–40 °C to +200 °C	±2	As above	10 s
Diesel fuel temperature sensor	Thermistor	–40 °C to +200 °C	±2	40 to +200	10 s
Diesel exhaust temperature sensor	Cr/Al thermocouple	–40 °C to +750 °C	±2	–40 to +750	10 s

Table 1.1 *continued*

Ambient air temperature sensor	Thermistor	–40 °C to +100 °C	±2	–40 to +100	10 s
Distributor-mounted timing/speed/trigger sensors	Hall effect *or* optical *or* eddy current *or* variable reluctance	Zero to maximum engine speed	±1	–40 to +180	N/A
Crankshaft-mounted timing/speed/trigger sensors	As above	As above	±1	–40 to +180	N/A
Road speed sensor: –speedometer cable/ gearbox fitting	Optical *or* Hall effect *or* reed switch	As above	±1	–40 to +125	N/A
Speed-over-ground sensor	Optical *or* radar	Zero to max. vehicle speed	±1	–40 to +125	N/A
Inlet manifold air-mass flow (unidirectional)	Vanemeter *or* hot wire *or* hot film	10 to 100 kg/h *and* 20 to 400 kg/h (two ranges)	±2 ±2	–40 to +125	35 ms for vanemeter, 5 ms for others.
Inlet manifold air-mass flow (bidirectional)	Ultrasonic *or* corona discharge *or* ion flow	±200 kg/h	±2	–40 to +125	1 ms

Table 1.1 *CONTINUED*

Accelerator pedal position sensor	Potentiometer	0–5 k from min. to max. Pedal travel	±1	–40 to +125	N/A
Throttle position sensor	Potentiometer	0–4 k from closed to open throttle	±3	–40 to +125	N/A
Gear selector position sensor	Microswitch *or* potentiometer	8 position selection *or* 0–5 k	±1	–40 to +150	N/A
Gear selector hydraulic valve position sensor	Optical encoder	8 position selection	±2	–40 to +125	N/A
EGR[1*] valve position sensor	Linear displacement potentiometer	0–10 mm	±2	–40 to +125	N/A

TABLE 1.1 *CONTINUED*

Closed throttle/full throttle sensors	Microswitches	N/A	N/A	–40 to +125	N/A
Engine knock sensor (gas engines)	Piezoelectric accelerometer	5–10 kHz, up to 1000 g	N/A	–40 to +125	Depends on resonant frequency
Engine knock and misfire sensor	Ionization measurement in cylinder or exhaust manifold	N/A	N/A	–40 to +150 (externally). Probe exposed to combustion gas temperatures	20 μs
Exhaust gas oxygen content sensor	Zirconium dioxide ceramic with platinum electrodes *or* titanium disks in aluminum	50% to 150% stoichiometric air-fuel ratio	3%	+300 to +850	50 ms
Exhaust gas oxygen content sensor for lean-burn operation	Zirconium dioxide oxygen pumping device with heater	14:1 to 30:1 air-fuel ratio	1%	+300 to +850	50 ms

TABLE 1.1 *CONTINUED*

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* Exhaust Gas Recirculation

sensor connected to the crankshaft. The pressure and speed signals provide inputs to a microprocessor, which is programmed to look up the optimum advance angle from a three-dimensional table relating speed, load, and advance angle stored in the microprocessor's memory (see figure 1.3 for an example). By this means significant improvements in engine operation and economy can be obtained. A number of designs of manifold pressure sensor have been used for this system, including devices based on capacitive, inductive, and potentiometric techniques. The most widely used approach is to employ a silicon diaphragm with integral silicon strain gauges, or to use a capacitive deflection sensing method [4]. In both of these sensors, a disk of silicon is etched to form a thin diaphragm (see figure 1.4) to which the pressure is applied. The strain gauges are integrated onto the disk, or a second capacitive plate is added. This technique produces a reliable low-cost device with a good resistance to the high-temperature, high-vibration conditions under which it has to operate.

2.1.2. Knock Sensing

When an ignition system with electronic advance control is optimized for best performance and economy, it can, under some conditions, be set sufficiently far advanced to cause a condition known as "knocking." Under these conditions premature high-rate combustion ("detonation") takes place, which, because of the rapid pressure increase, can quickly cause physical damage to vulnerable structures within

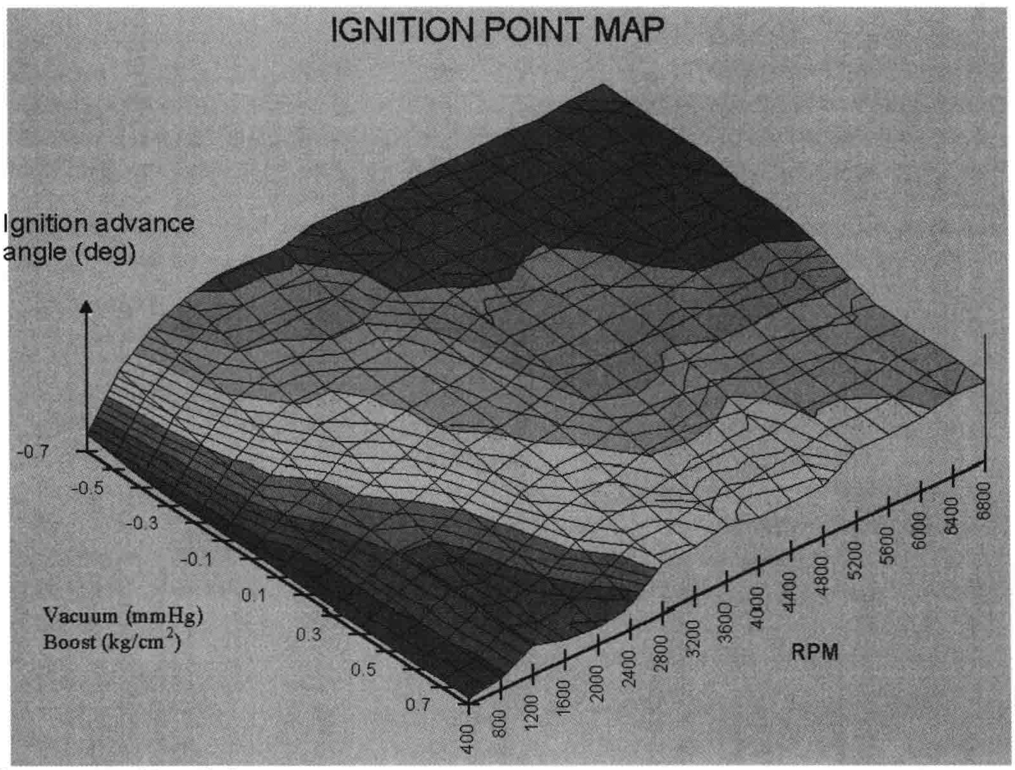

Figure 1.3. Ignition timing map