INDUSTRIAL PROCESS MEASURING INSTRUMENTS

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PREFACE

Industrial Process Measuring Instruments has been prepared for the purpose of supplying the application engineer with information needed when selecting primary instruments for industrial process measurement, along with suggestions for their application. Characteristic and accuracy curves are given where the text justifies them. Elsewhere, tables give ranges, pressure limitations, and temperature limitations.

The text is organized so that each chapter is divided into sections. In each section the principle of design of a particular type of the various manufacturers' measuring instruments is discussed, together with suggestions for its application in industrial processing. Preparing the text in this manner enables the book to be used both as a teaching text and as a home study course, as well as a reference for the practical application engineer. Vocational schools, trade schools, and technical institutes will also find the book well suited to their use. The need for a compilation of such material as contained in *Industrial Process Measuring Instruments* for use in company-sponsored training courses has been recognized for many years by the industrial processing industry.

The book is not intended to be all-inclusive but does give a cross section of industrial primary measuring instruments manufactured by 44 instrument companies. In this manner the author has attempted, without repetition, to bring to the attention of the application engineer and student the various methods available for making industrial process measurements.

Grady C. Carroll

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Chapter 1

DIFFERENTIAL PRESSURE MEASURING ELEMENTS

INTRODUCTION

In this chapter differential pressure measuring elements and their application are discussed. Elements included are diaphragm transmitting, bellows, liquid-filled bellows, inverted-bell, mercury-manometer, and ring-balance types.

The diaphragm-type pneumatic transmitting element is one of the most popular instruments for measuring differential pressures in processing plants. It is especially favored in flow-measuring systems where differential pressure producing elements such as orifice plates, venturis, flow nozzles, etc., are used. The instrument is extremely rugged in its design and sufficiently accurate for industrial process measurements. One advantage it has over certain other types of elements is its overrange protection. Usually it is designed to take overrange pressures up to the pressure for which the body is designed, which may be 1,500 psi. It is available in pneumatic and electrical transmission from certain manufacturers, and each has its field of application. The pneumatic type may be preferred where time lags of measurement are unimportant and transmission is over short distances. The electrical type, on the other hand, may be desirable because of its high speed of transmission and ability to transmit over distances far exceeding that of the pneumatic type. The Bailey Meter Company has a force-balance differential pressure transmitter which produces an output signal that is the square root of the measured differential pressure. The Republic Flow Meter Company has a transmitter of different design but with the same type of output. Such transmitters are extremely valuable where it is desired to have an output signal that is proportional to the volume of the measured material.

The bellows-type differential pressure measuring element has a high response to changes in differential pressure but is difficult to protect against overranges. Therefore its field of application is more limited than that of the diaphragm-type transmitter. The bellows-type element, however, is available with pneumatic and electrical transmission. The advantages of the two methods of transmission are comparable to those mentioned under the diaphragm type.

The liquid-filled-type differential pressure measuring element consists of two bellows connected together and completely filled with a liquid. When a differential pressure is applied, one bellows is contracted while the other expands. Such elements are protected against overranges equal to the pressure for which the body is designed.

The inverted-bell-type differential pressure element as discussed in this chapter is used for low differential pressure ranges, with the exception of the Bailey Meter Company Ledoux bell and the Minneapolis-Honeywell characterized bell. The Ledoux bell is designed in such a manner that its output is recorded as the square root of the measured differential pressure. The characterized bell manufactured by Minneapolis-Honeywell Regulator Company, Inc., also has an output that is proportional to the square root of the measured differential pressure. These instruments are used quite extensively in power-generating plants and in other processes where it is desirable to have the meter read directly in volume of the measured material. The disadvantage of such instruments for application in processing plants stems from the fact that the bells are sealed in mercury and many chemicals are not compatible with mercury.

The variable-area-type element is designed upon the principle of the conventional rotameter. When the instrument is connected across a differential pressure producing device such as an orifice plate, flow nozzle, venturi tube, etc., its output becomes linear to the volume of the flowing fluid. Actually, it provides a bypass for a small flow of the measured material around the primary element, which may be an advantage in some cases.

Mercury-manometer-type elements are reliable for differential pressure measurement, but they also operate with mercury in contact with the measured material and, as mentioned above, many chemicals are not compatible with mercury. However, for the measurement of natural gas, water, steam condensate, steam, etc., they are inexpensive, reliable instruments.

The ring-balance meter is a radial torque meter which may be used for the measurement of steam, steam condensate, water, or any clean material. It is also available with pneumatic transmitting units. However, in chemical processing plants its use is limited in certain cases because of the diameter of the tubes which are used to transmit the differential pressure to the ring-balance element. In most cases these tubes are small in diameter and they would plug if slurries and dirty materials were measured.

1-1. DIAPHRAGM-TYPE ELEMENT

Transmitting, Pneumatic

Bailey Meter Company

Principle of Design. Shown in Fig. 1-1 is a simplified schematic diagram of a Bailey Meter Company differential pressure transmitter of the pneumatic force-balance type.

Motion of the measuring diaphragm moves the force beam and vane. Movement of the force beam changes the vane-and-nozzle relationship,

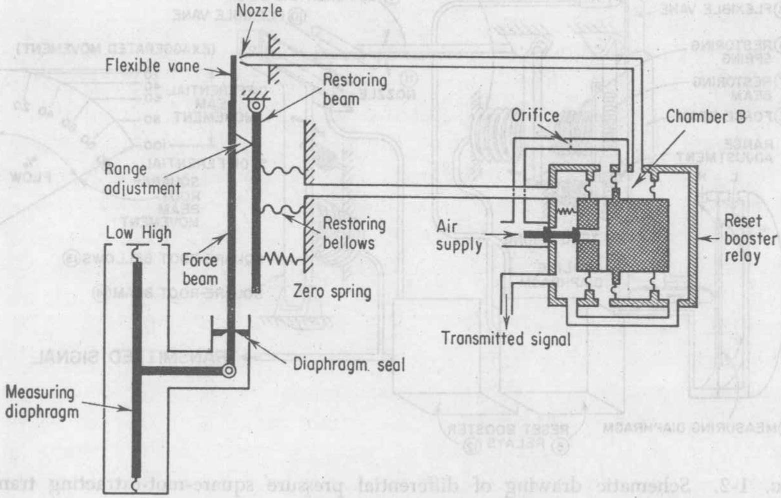

FIG. 1-1. Schematic drawing of differential pressure transmitter, pneumatic type. (*Bailey Meter Company.*)

thus changing the nozzle air flow, which produces a change in the booster valve output pressure. The booster output pressure goes to a restoring bellows and repositions the restoring beam. Repositioning the restoring beam, which is in contact with the force beam through the range adjustment, moves the measuring diaphragm back to its normal position and restores the vane nozzle at balance distance. The booster output pressure, which is directly proportional to the differential pressure, is also transmitted to indicating, recording, and/or controlling equipment.

The range span adjustment sets the maximum transmitted pressure signal at 15 or 27 psi, depending upon the pneumatic range when the maximum differential pressure range is applied to the measuring diaphragm. The zero adjustment sets the minimum transmitted pressure signal at 3 psi when zero differential pressure is applied to the measuring diaphragm.

Bailey Meter Company

Principle of Design. Shown schematically in Fig. 1-2 is a Bailey Meter Company force-balance transmitter designed to produce an output signal that is proportional to the volume flowing through a primary device such as orifice plate, flow nozzle, or venturi rather than the difference in pressure across such a device.

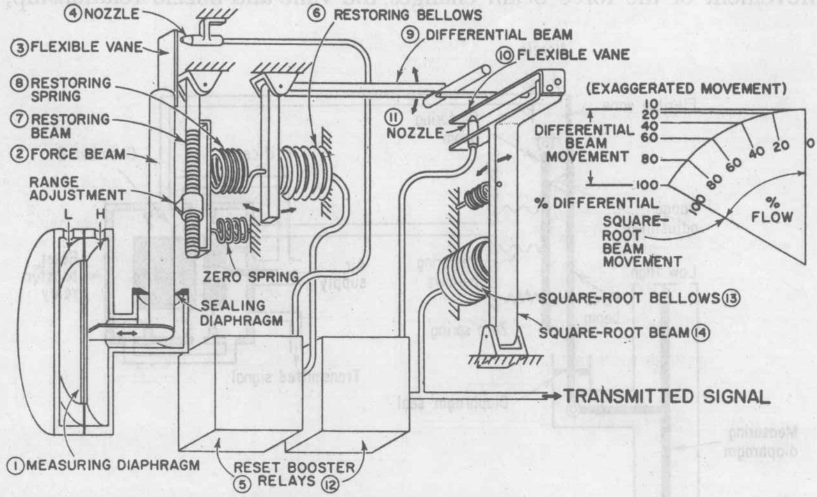

FIG. 1-2. Schematic drawing of differential pressure square-root-extracting transmitter, pneumatic type. (*Bailey Meter Company.*)

In operation, the diaphragm 1 moves to the left, at the same time moving the force beam 2 and vane 3 to the right, which decreases the distance between the vane and nozzle 4. This increases the nozzle back pressure, resulting in an increased output from the booster relay 5. An increased booster output pressure to the restoring bellows 6 forces the restoring beam 7 to the left because of the restoring spring 8, repositioning the force beam 2 and vane 3 and restoring "at balance" the vane-nozzle relationship. As the force beam 2 moves, it repositions the diaphragm 1 to its normal center position.

An increased booster output pressure to the restoring bellows 6 moves the differential beam 9 downward, forcing vane 10 closer to nozzle 11. This increases the nozzle back pressure, resulting in an increased output pressure from the booster 12. An increased booster output pressure is admitted to the restoring bellows 13, which moves the square-root beam

14 on an arc until the vane-nozzle "at balance" distance is restored and the transmitter is at balance.

The square-root beam 14 moves a distance proportional to the square root of the distance moved by the differential beam 9. The schematic is designed to exaggerate the movements for the sake of illustration. Thus the pneumatic output signal is proportional to the square root of the differential pressure as it appears across the measuring diaphragm, which means that the output would be proportional to the volume of a fluid flowing through an orifice, flow nozzle, or venturi to which the transmitter is connected.

Fischer and Porter Company

Principle of Design. A cutaway view of a Fischer and Porter force-balance differential pressure transmitter is shown in Fig. 1-3. The unit

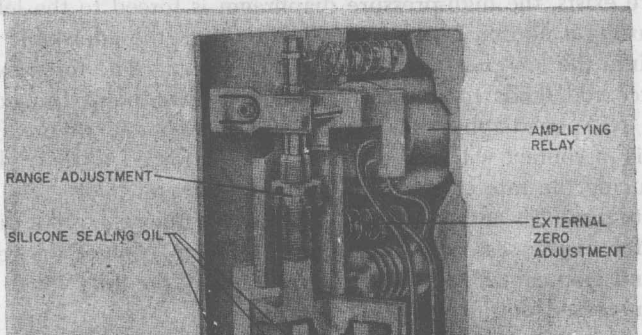

FIG. 1-3. Cutaway view of differential pressure transmitter, pneumatic type. (*Fischer and Porter Company.*)

consists of two metal diaphragms located on either side of a body forging, force rod, detecting pilot, air relay, force plate, and feedback bellows. The force rod extends through a Ni-Span diaphragm into a chamber which is enclosed by the two measuring diaphragms. Located within this chamber and connected to the force rod is a tension rod which in conjunction with the Ni-Span sealing diaphragm provides a pivot around which the force rod tends to rotate when a differential pressure is applied to the measuring diaphragm.

The chamber enclosed by the measuring diaphragms and the sealing diaphragm is completely filled with a silicon oil. An adjustable damping screw is located in a drilled passage between the two measuring diaphragms. The measuring diaphragms are protected against overrange in either direction at a value equal to the working pressure of the unit. The temperature rating of the unit is set at minus 20 to plus 300°F.

In operation, a 20-psi air-supply pressure is applied to the air relay, and the two pressures of which the difference is to be measured are connected to the proper body connections. Any difference in pressure between the body connections will result in a force being exerted on the force rod by the diaphragms, the value of which will be proportional to the difference in pressure across the diaphragms. When a difference in pressure exists, the high-pressure diaphragm is forced to the left in Fig. 1-3, causing a portion of the oil to flow through the adjustable damping screw into the low-pressure side of the chamber. The force exerted on the force rod tends to rotate it around its pivot point formed by the sealing Ni-Span diaphragm. Thus the extended end of the force rod which is in contact with the detecting pilot is forced to the right, thereby reducing the rate of vent through the detecting pilot. The reduced vent rate produces an increased pressure above the relay pilot diaphragm which forces the seat of the automatic bleed to contact the relay pilot valve and momentarily close the bleed and open the inlet valve, resulting in an increased output pressure.

Since the output pressure acts on the feedback bellows, its increased force is applied to the force plate where it is transmitted to the force rod. When the force of the feedback bellows equals that created by the differential pressure across the measuring diaphragms, the unit will be at balance in a null position. It is obvious that for every value of differential pressure within the range of the transmitter, there will be a corresponding output pressure which can be transmitted several hundred feet and recorded or indicated by a 3- to 15-psi receiving instrument as differential pressure or the square root of the differential pressure, depending on the type of scale or chart used.

The Foxboro Company

Principle of Design. Figure 1-4 shows a cutaway view of the Foxboro model 13A differential pressure transmitter which operates on the pneumatic force-balance principle. The measuring diaphragm assembly consists of a twin-diaphragm capsule. This capsule consists of two type 316 stainless-steel diaphragms seam-welded to a type 316 stainless core, the diaphragms and core having convolutions. The space between the diaphragms and the core is filled completely with a temperature-stable silicon liquid. This liquid protects the twin diaphragms against overrange on either side of the capsule. The core to which the diaphragms are welded has a self-centering ring around its rim. When assembled, this core is held firmly between the high- and low-pressure castings. In this core are provided small holes so that the sealed-in fluid can pass back and forth. This feature reduces line noise to a minimum. Therefore, damping at the receiving instrument is usually not necessary. The force produced by a differential pressure across the measuring diaphragm is transmitted through a force bar to which the twin-diaphragm capsule is connected by C flexure.

A pressure seal is provided on the force bar by a metal diaphragm made from Elgiloy alloy. The top of the force bar is connected to a tension flexure frame on which the flapper is mounted. The nozzle arrangement is securely fastened to a casting parallel to the force bar.

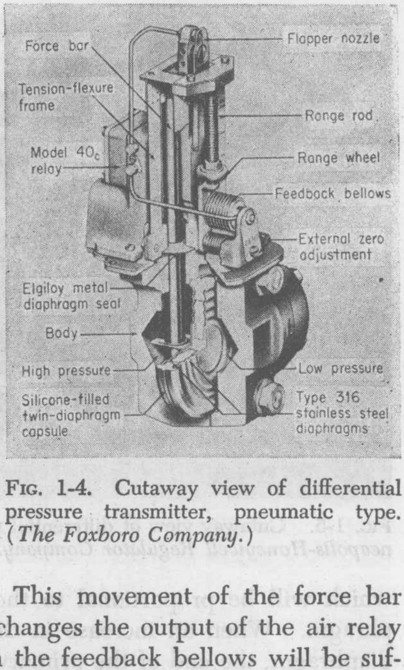

FIG. 1-4. Cutaway view of differential pressure transmitter, pneumatic type. (*The Foxboro Company.*)

The pneumatic transmitting system consists of a feedback bellows, zero adjustment, air-relay valve, and nozzle. From Fig. 1-4 it can be seen that any force created by a differential pressure across the measuring diaphragms will be transmitted through the force bar. This movement of the force bar operates the flapper, which in turn changes the output of the air relay in order that the pressure created in the feedback bellows will be sufficient to balance exactly the force exerted by the differential pressure across the measuring diaphragm.

Thus for every value of differential pressure applied to the measuring diaphragm within range of the instrument, there will be a corresponding output signal that can be transmitted over a distance of several hundred feet and recorded or indicated as differential pressure.

Minneapolis-Honeywell Regulator Company

Principle of Design. Shown in Fig. 1-5 is a cutaway view of a pneumatic force-balance differential pressure transmitter of the Minneapolis-

Honeywell Regulator Company design. The unit consists of a low-pressure chamber, measuring diaphragm 1, high-pressure chamber 2, primary beam 3, mounting plate, cross-spring fulcrum, sealing bellows, secondary beam 4, calibration groove, balancing bellows 5, nozzle 6, flapper 7, pilot relay 8, damping dashpot 9, range adjustment 10, and zero adjustment.

In operation, the two pressures of which the difference is to be measured are connected to either side of the measuring diaphragm 1. The higher of the two is connected above the diaphragm. The instrument functions to convert the force exerted on the primary beam 3 by the measuring diaphragm 1 into a pneumatic output signal, the value of

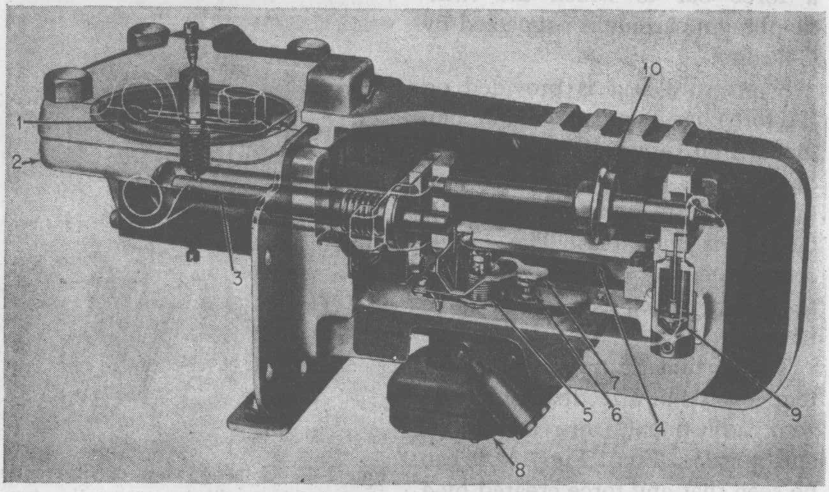

FIG. 1-5. Cutaway view of differential pressure transmitter, pneumatic type. (*Minneapolis-Honeywell Regulator Company.*)

which will be proportional to the differential pressure across the diaphragm. When an increase in differential pressure appears across the diaphragm, the end of the primary beam connected to the damping unit is forced down. Since the motion of the primary beam is transmitted through the range adjustment 10 to the secondary beam 4 and the nozzle 6, the flapper 7 is lowered until it contacts the nozzle, which reduces the rate of vent through the nozzle, resulting in an increase in the nozzle back pressure. The back pressure is applied to the pilot-relay diaphragm where it is amplified and becomes the transmitter output signal.

A feedback is provided between the output and the balancing bellows. As the output pressure increases, the upward force exerted on the secondary beam 4 by the balancing bellows also increases. When the upward force of the bellows applied to the primary beam 3 is exactly