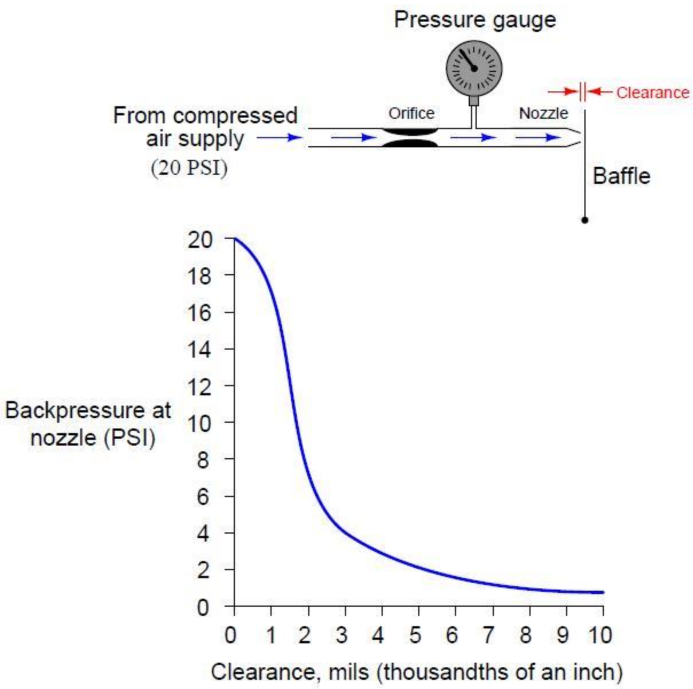
Pneumatic Instrumentation - Pneumatic Sensing Elements

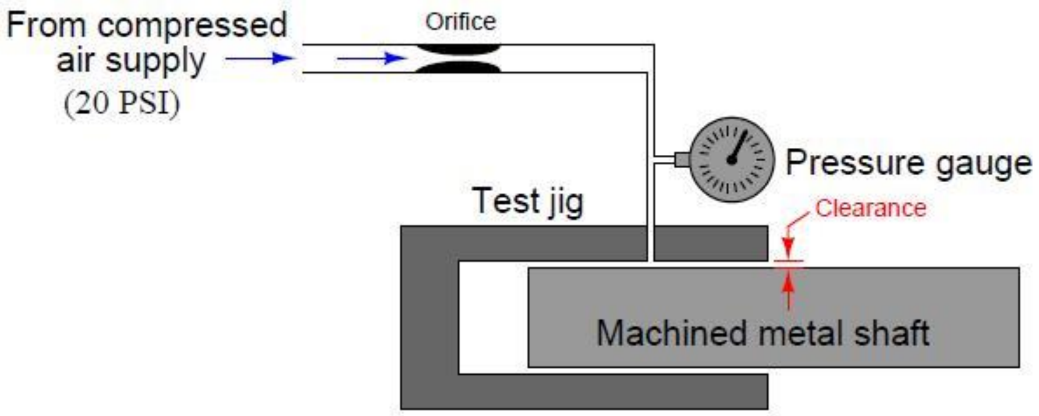
Most pneumatic instruments use a simple but highly sensitive mechanism for converting mechanical motion into variable air pressure: the baffle-and-nozzle assembly (sometimes referred to as a flapper- and-nozzle assembly). A baffle is nothing more than a flat object obstructing the flow of air out of a small nozzle by close proximity:



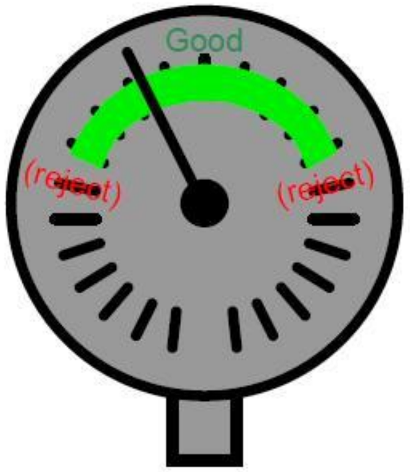
The physical distance between the baffle and the nozzle alters the resistance of air flow through the nozzle. This in turn affects the air pressure built up inside the nozzle (called the nozzle backpressure). Like a voltage divider circuit formed by one fixed resistor and one variable resistor, the baffle/nozzle mechanism “divides” the pneumatic source pressure to a lower value based on the ratio of restrictiveness between the nozzle and the fixed orifice.

This crude assemblage is surprisingly sensitive, as shown by the graph. With a small enough orifice, just a few thousandths of an inch of motion is enough to drive the pneumatic output between its saturation limits. Pneumatic transmitters typically employ a small sheet-metal lever as the baffle. The slightest motion imparted to this baffle by changes in the process variable (pressure, temperature, flow, level, etc.) detected by some sensing element will cause the air pressure to change in response.

The principle behind the operation of a baffle/nozzle mechanism is often used directly in quality control work, checking for proper dimensioning of machined metal parts. Take for instance this shaft diameter checker, using air to determine whether or not a machined shaft inserted by a human operator is of the proper diameter after being manufactured on an assembly line:



If the shaft diameter is too small, there will be excessive clearance between the shaft and the inside diameter of the test jig, causing less air pressure to register on the gauge. Conversely, if the shaft diameter is too large, the clearance will be less and the gauge will register a greater air pressure because the flow of air will be obstructed by the reduced clearance. The exact pressure is of no particular consequence to the quality-control operator reading the gauge. What does matter is that the pressure falls within an acceptable range, reflecting proper manufacturing tolerances for the shaft. In fact, just like the 3-15 PSI "receiver gauges" used as pneumatic instrument indicators, the face of this pressure gauge might very well lack pressure units (such as kPa or PSI), but rather be labeled with a colored band showing acceptable limits of mechanical fit:

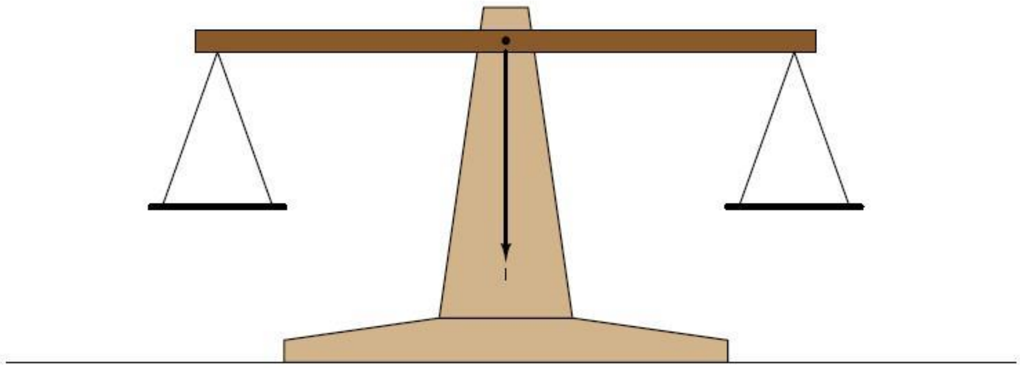


This is another example of the analogue nature of pneumatic pressure signals: the pressure registered by this gauge represents a completely different variable, in this case the mechanical fit of the shaft to the test jig.

Although it is possible to construct a pneumatic instrument consisting only of a baffle/nozzle mechanism, this is rarely done. Usually the baffle/nozzle mechanism is but one of several components that comprise a "balancing" mechanism in a pneumatic instrument. It is this concept of self-balancing that we will study next

Pneumatic Instrumentation - Self-Balancing Pneumatic Instrument Principles

A great many precision instruments use the principle of balance to measure some quantity. Perhaps the simplest example of a balance-based instrument is the common balance-beam scale used to measure mass in a laboratory:

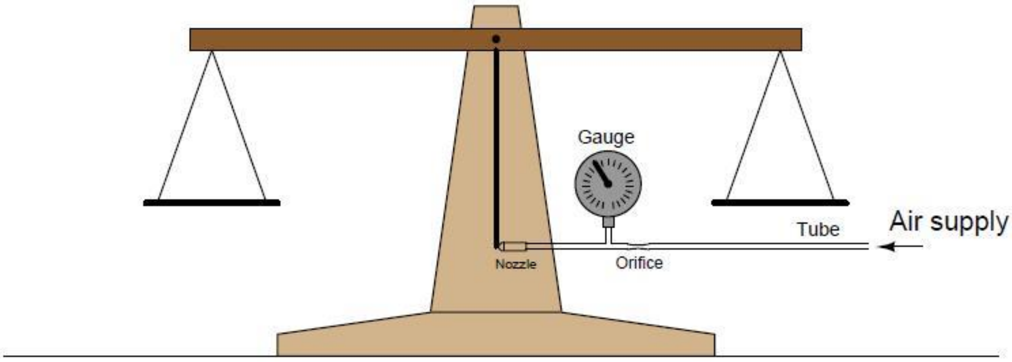


A specimen of unknown mass is placed in one pan of the scale, and precise weights are placed in the other pan until the scale achieves a condition of balance. When balance is achieved, the mass of the specimen is known to be equal to the sum total of mass in the other pan. An interesting detail to note about the scale itself is that it has no need of routine calibration. There is nothing to “drift” out of spec which would cause the scale to read inaccurately. In fact, the scale itself doesn’t even have a gauge to register the mass of the specimen: all it has is a single mark indicating a condition of balance. To express this more precisely, the balance beam scale is actually a differential mass comparison device, and it only needs to be accurate at a single point: zero. In other words, it only has to be correct when it tells you there is zero difference in mass between the specimen and the standard masses piled on the other pan.

The elegance of this mechanism allows it to be quite accurate. The only real limitation to accuracy is the certainty to which we know the masses of the balancing weights.

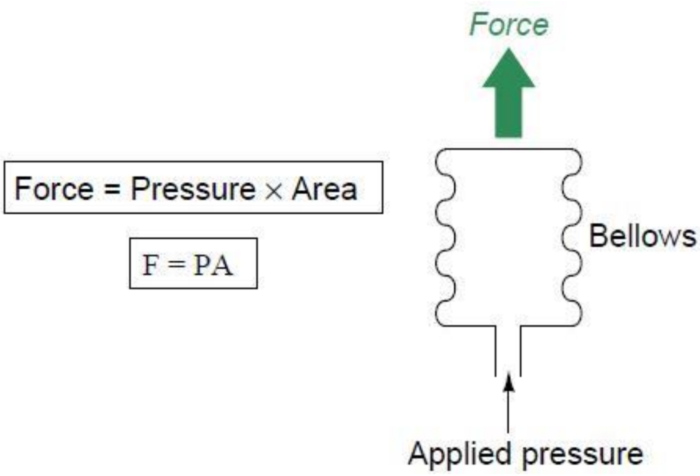
Imagine being tasked with the challenge of automating this laboratory scale. Suppose we grew weary of having to pay a lab technician to place standard weights on the scale to balance it for every new measurement, and we decided to find a way for the scale to balance itself. Where would we start? Well, we would need some sort of mechanism to tell when the scale was out of balance, and another mechanism to change weight on the other pan whenever an out-of-balance condition was detected.

The baffle/nozzle mechanism previously discussed would suffice quite well as a detection mechanism. Simply attach a baffle to the end of the pointer on the scale, and attach a nozzle adjacent to the baffle at the “zero” position (where the pointer should come to a rest at balance):



Now we have a highly sensitive means of indicating when the scale is balanced, but we still have not yet achieved full automation. The scale cannot balance itself, at least not yet.

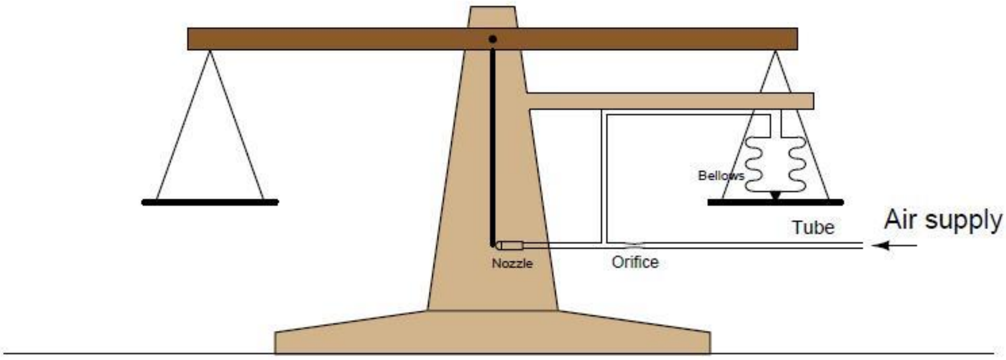
What if, instead of using precise, machined, brass weights placed on the other pan to counter the mass of the specimen, we used a pneumatically-actuated force generator operated by the backpressure of the nozzle? An example of such a "force generator" is a bellows: a device made of thin sheet metal with circular corrugations in it, such that it resembles the bellows fabric on an accordion. Pneumatic pressure applied to the interior of the bellows causes it to elongate. If the metal of the bellows is flexible enough so it does not naturally restrain the motion of expansion, the force generated by the expansion of the bellows will almost exactly equal that predicted by the force-pressure-area equation:



A photograph of a brass bellows unit appears here, the bellows taken from a Foxboro model 130 pneumatic controller:

If the bellows' expansion is externally restrained so it does not stretch appreciably – and therefore the metal never gets the opportunity to act as a restraining spring – the force exerted by the bellows on that restraining object will exactly equal the pneumatic pressure multiplied by the cross-sectional area of the bellows' end.

Applying this to the problem of the self-balancing laboratory scale, imagine fixing a bellows to the frame of the scale so it presses downward on the pan where the brass weights normally go, then connecting the bellows to the nozzle backpressure:

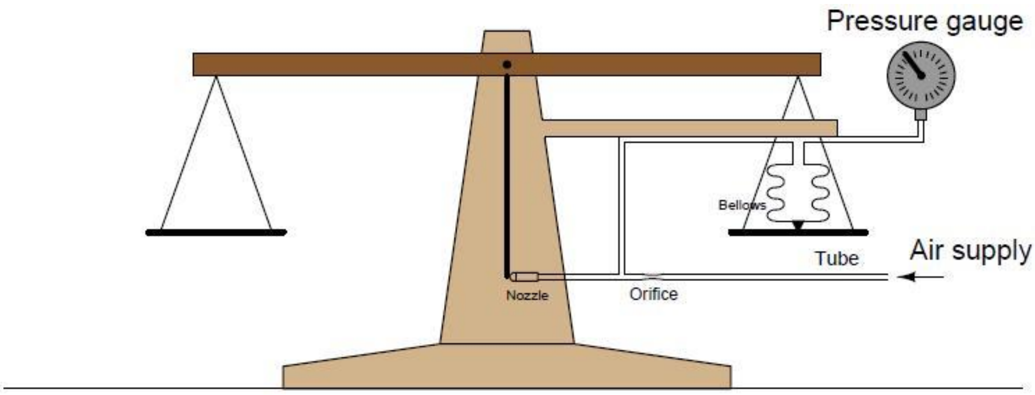


Now the scale will self-balance. When mass is added to the left-hand pan, the pointer (baffle) will move ever so slightly toward the nozzle until enough backpressure builds up behind the nozzle to make the bellows exert the proper amount of balancing force and bring the pointer back (very close) to its original balanced condition. This balancing action is entirely automatic: the nozzle backpressure adjusts to whatever it needs to be in order to keep the pointer at the balanced position, applying or venting pressure to the bellows as needed to keep the system in a condition of equilibrium. What we have created is a negative feedback system, where the output of the system (nozzle backpressure) continuously adjusts to match and balance the input (the applied mass).

This is all well and good, but how does this help us determine the mass of the specimen in the left-hand pan? What good is this self-balancing scale if we cannot read the balancing force? All we have achieved so far is to make the scale self-balancing. The next step is making the balancing force readable to a human operator.

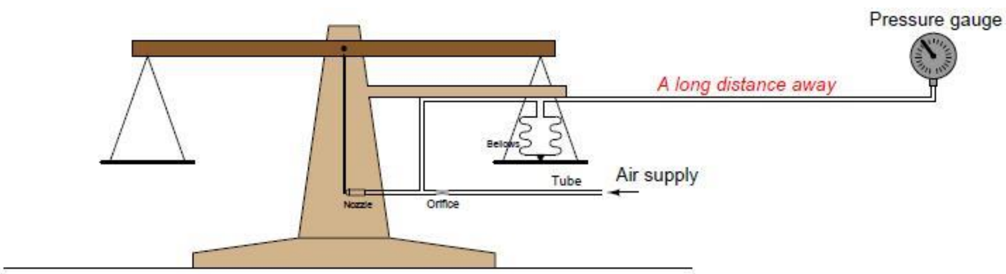
Before we add the final piece to this automated scale, it is worthwhile to reflect on what has been done so far. By adding the baffle/nozzle and bellows mechanisms to the scale, we have abolished the need for brass weights and instead have substituted air pressure. In effect, the scale translates the specimen's mass into a proportional, analogue, air pressure. What we really need is a way to now translate that air pressure into a human-readable indication of mass.

The solution is simple: add the pressure gauge back to the system. The gauge will register air pressure, but this time the air pressure will be proportionately equivalent to specimen mass. In honor of this proportionality, we may label the face of the pressure gauge in units of grams (mass) instead of PSI or kPa (pressure):



It is very important to note how the pressure gauge performs an entirely different function now than when it did prior to the addition of the feedback bellows. With just a baffle-nozzle mechanism at work, the pressure gauge was hyper-sensitive to any motion of the scale's balance beam – it served only as a highly sensitive indicator of balance. Now, with the addition of the feedback bellows, the pressure gauge actually indicates how much mass is in the specimen pan, not merely whether the scale is balanced or not. As we add more mass to the specimen pan, the gauge's indication proportionately increases. As we take away mass from the specimen pan, the gauge's indication proportionately decreases.

Although it may seem as though we are done with the task of fully automating the laboratory scale, we can go a step further. Building this pneumatic negative-feedback balancing system provides us with a capability the old manually-operated scale never had: remote indication. There is no reason why the indicating gauge must be located near the scale. Nothing prevents us from locating the receiver gauge some distance from the scale, and using long lengths of tubing to connect the two:



By equipping the scale with a pneumatic self-balancing apparatus, we have turned it into a pneumatic mass transmitter, capable of relaying the mass measurement in pneumatic, analog form to an indicating gauge far away. This is the basic force-balance principle used in most pneumatic industrial transmitters to convert some process measurement into a 3-15 PSI pneumatic signal.

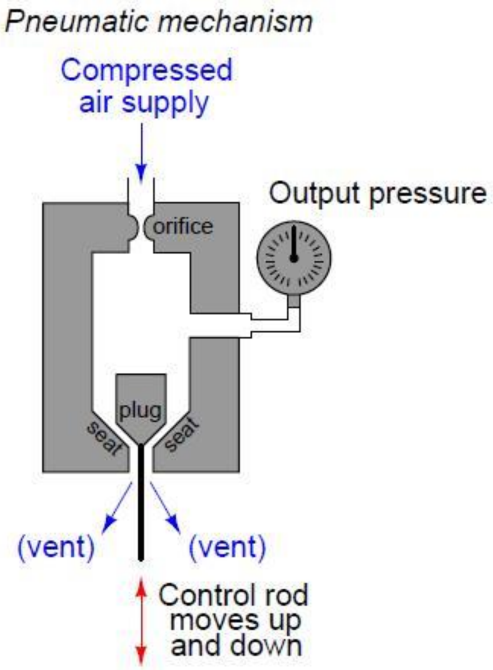
Pneumatic Instrumentation - Pilot Valves and Pneumatic Amplifying Relays

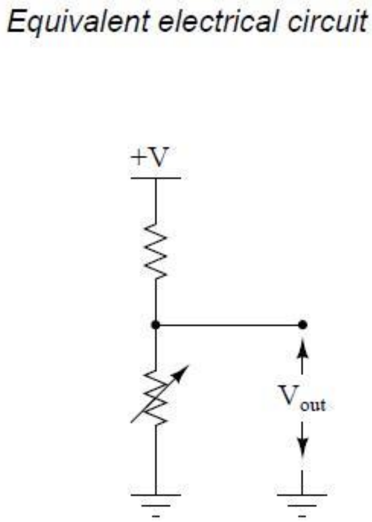
Self-balancing mechanisms such as the fictitious pneumatic laboratory scale in the previous section are most accurate when the imbalance detection mechanism is most sensitive. In other words, the more aggressively the baffle/nozzle mechanism responds to slight out-of-balance conditions, the more precise will be the relationship between measured variable (mass) and output signal (air pressure to the gauge).

A plain baffle/nozzle mechanism may be made extremely sensitive by reducing the size of the orifice. However, a problem caused by decreasing orifice size is a corresponding decrease in the nozzle's ability to provide increasing backpressure to fill a bellows of significant volume. In other words, a smaller orifice will result in greater sensitivity to baffle motion, but it also limits the air flow rate available to fill the bellows, which makes the system slower to respond. Another disadvantage of smaller orifices is that they become more susceptible to plugging due to impurities in the compressed air.

An alternative technique to making the baffle/nozzle mechanism more sensitive is to amplify its output pressure using some other pneumatic device. This is analogous to increasing the sensitivity of a voltage-generating electrical detector by passing its output voltage signal through an electronic amplifier. Small changes in detector output become bigger changes in amplifier output which then causes our self-balancing system to be even more precise. What we need, then, is a pneumatic amplifier: a mechanism to amplify small changes in air pressure and convert them into larger changes in air pressure. In essence, we need to find a pneumatic equivalent of the electronic transistor: a device that lets one signal control another.

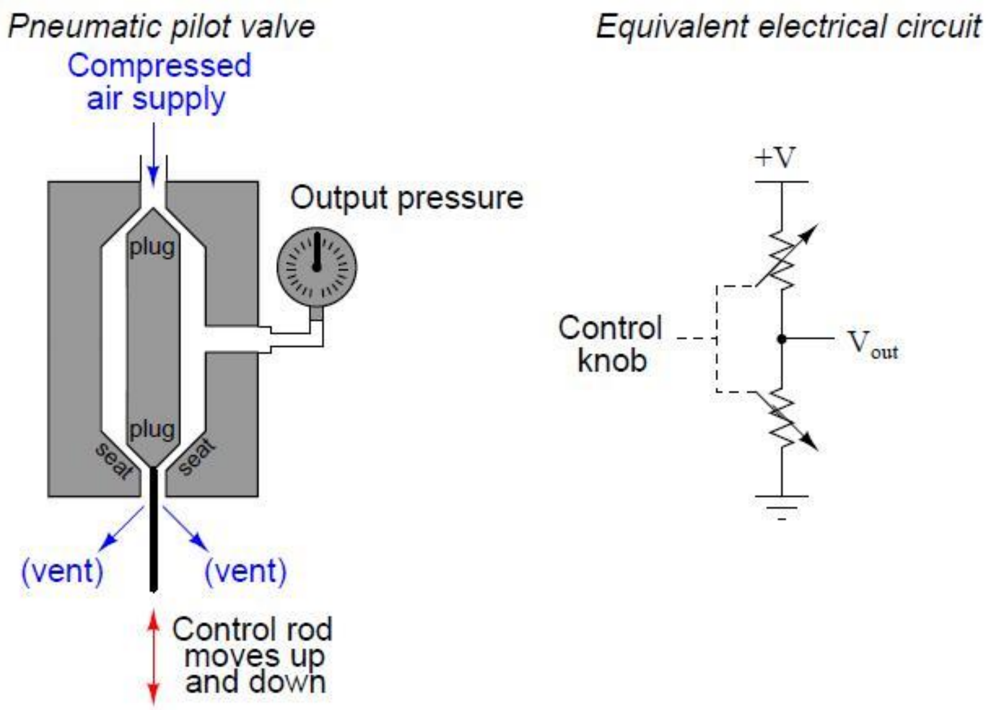
First, let us analyze the following pneumatic mechanism and its electrical analogue (as shown on the right):





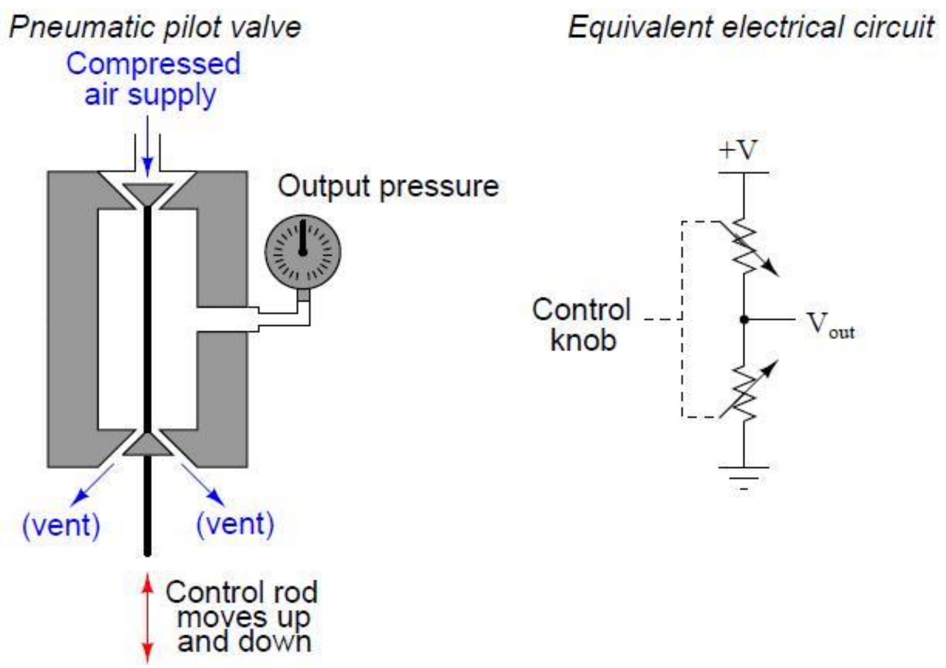
As the control rod is moved up and down by an outside force, the distance between the plug and the seat changes. This changes the amount of resistance experienced by the escaping air, thus causing the pressure gauge to register varying amounts of pressure. There is little functional difference between this mechanism and a baffle/nozzle mechanism. Both work on the principle of one variable restriction and one fixed restriction (the orifice) "dividing" the pressure of the compressed air source to some lesser value.

The sensitivity of this pneumatic mechanism may be improved by extending the control rod and adding a second plug/seat assembly. The resulting mechanism, with dual plugs and seats, is known as a pneumatic pilot valve. An illustration of a pilot valve is shown here, along with its electrical analogue (on the right):

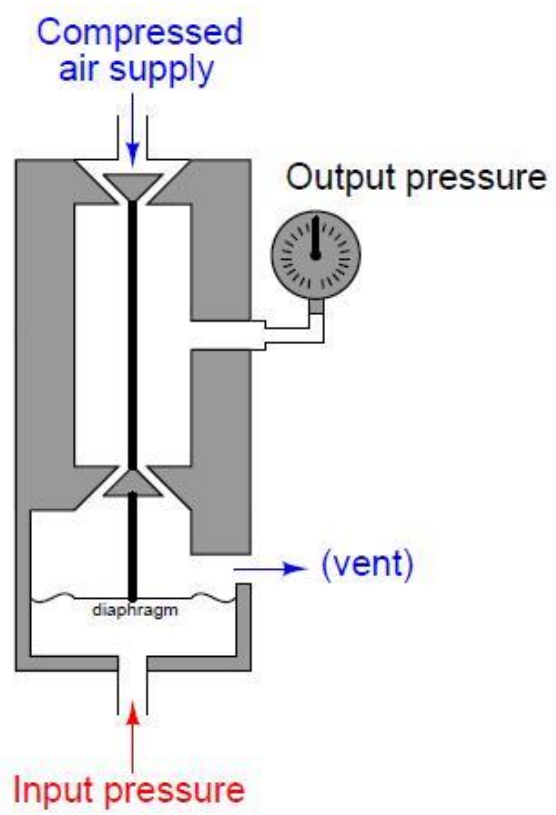


As the control rod is moved up and down, both variable restrictions change in complementary fashion. As one restriction opens up, the other pinches shut. The combination of two restrictions changing in opposite direction results in a much more aggressive change in output pressure as registered by the gauge.

A similar design of pilot valve reverses the directions of the two plugs and seats. The only operational difference between this pilot valve and the previous design is an inverse relationship between control rod motion and pressure:



At this point, all we've managed to accomplish is build a better baffle/nozzle mechanism. We still do not yet have a pneumatic equivalent of an electronic transistor. To accomplish that, we must have some way of allowing an air pressure signal to control the motion of a pilot valve's control rod. This is possible with the addition of a diaphragm, as shown in this illustration:

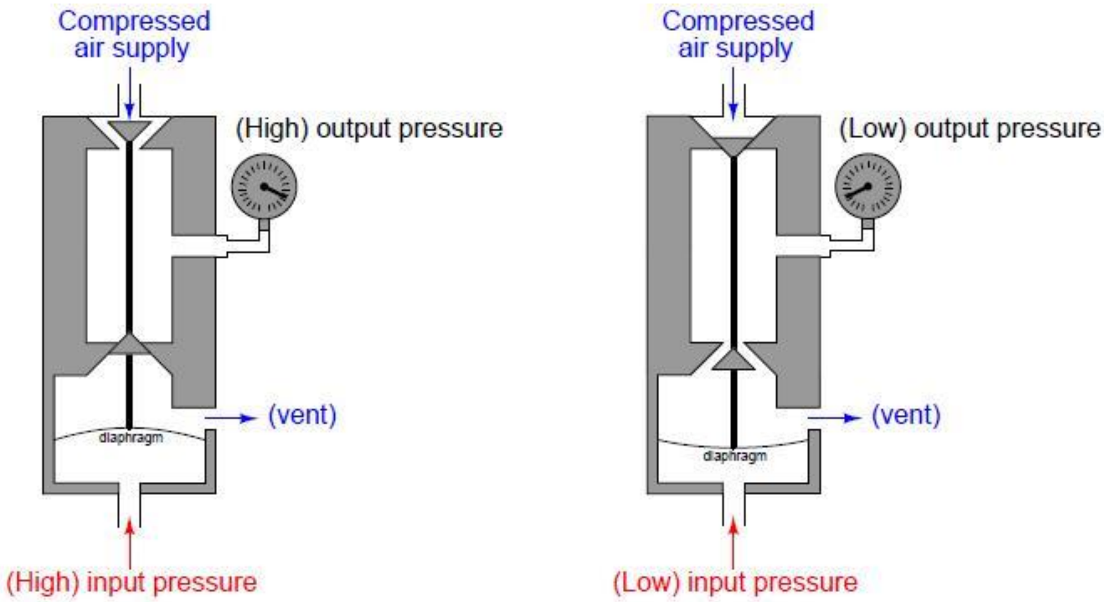


The diaphragm is nothing more than a thin disk of sheet metal, upon which an incoming air pressure signal presses. Force on the diaphragm is a simple function of signal pressure (P) and diaphragm area (A), as described by the standard force-pressure-area equation:

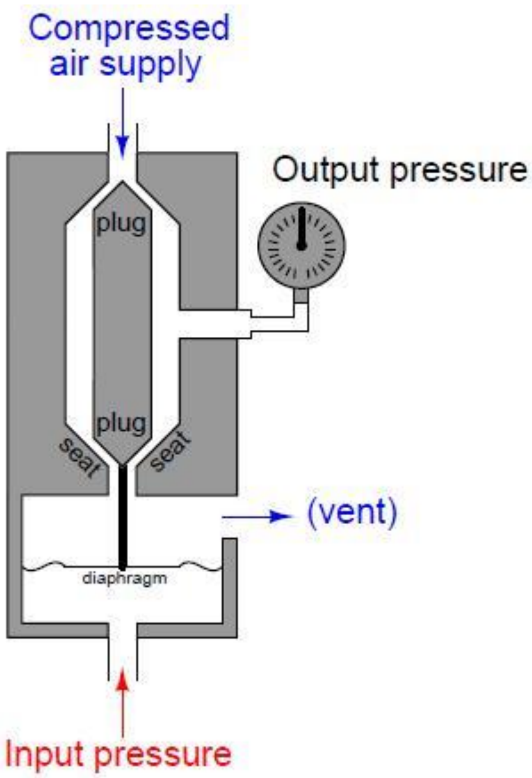
$$F = PA$$

If the diaphragm is taut, the elasticity of the metal allows it to also function as a spring. This allows the force to translate into displacement (motion), forming a definite relationship between applied air pressure and control rod position. Thus, the applied air pressure input will exert control over the output pressure. The addition of an actuating mechanism to the pilot valve turns it into a pneumatic relay, which is the pneumatic equivalent of the electronic transistor we were looking for.

It is easy to see how the input air signal exerts control over the output air signal in these two illustrations:



Since there is a direct relationship between input pressure and output pressure in this pneumatic relay, we classify it as a direct-acting relay. If we were to add an actuating diaphragm to the first pilot valve design, we would have a reverse-acting relay as shown here:

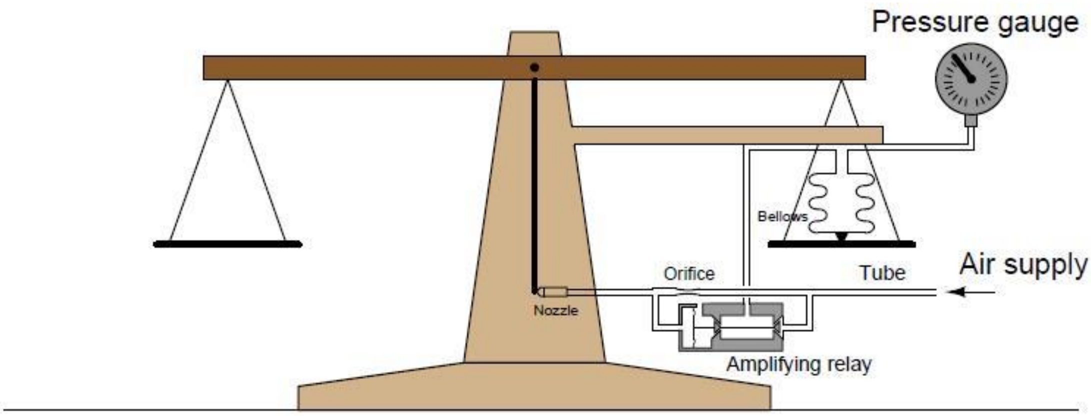


The gain (A) of any pneumatic relay is defined just the same as the gain of any electronic amplifier circuit, the ratio of output change to input change:

$$A = \frac{\Delta\text{Output}}{\Delta\text{Input}}$$

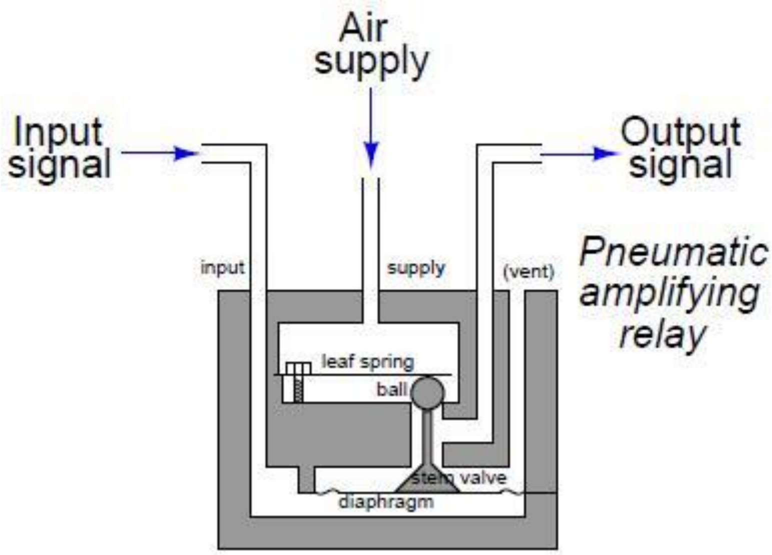
For example, if an input pressure change of Δ2 PSI results in an output pressure change of Δ12 PSI, the gain of the pneumatic relay is 6.

Adding a pneumatic pressure-amplifying relay to a force-balance system such as our hypothetical laboratory scale improves the performance of that pneumatic system:



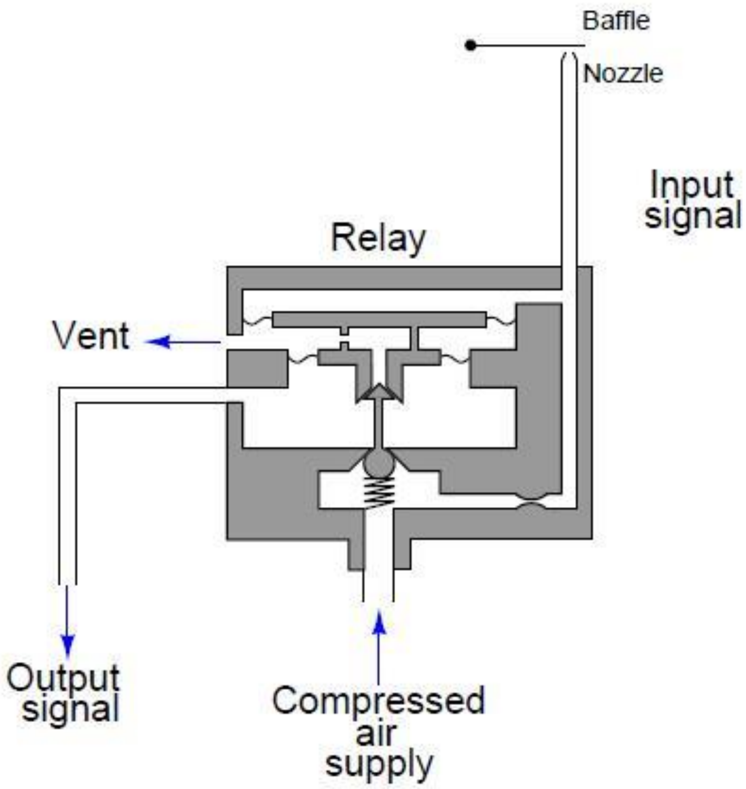
Since the relay amplifies the nozzle's backpressure, the force-balancing bellows responds even more aggressively than before (without the relay) to any change in baffle position. This makes the scale more sensitive, better able to sense small changes in applied mass than without an amplifying relay.

The Foxboro corporation designed a great many of their pneumatic instruments to used a very sensitive amplifying relay:



The motion of the diaphragm actuated a pair of valves: one with a cone-shaped plug and the other with a metal ball for a plug. The ball-plug allowed supply air to go to the output port, while the cone-shaped “stem valve” plug vented excess air pressure to the vent port.

The Fisher corporation used a different style of amplifying relay in some of their pneumatic instruments:



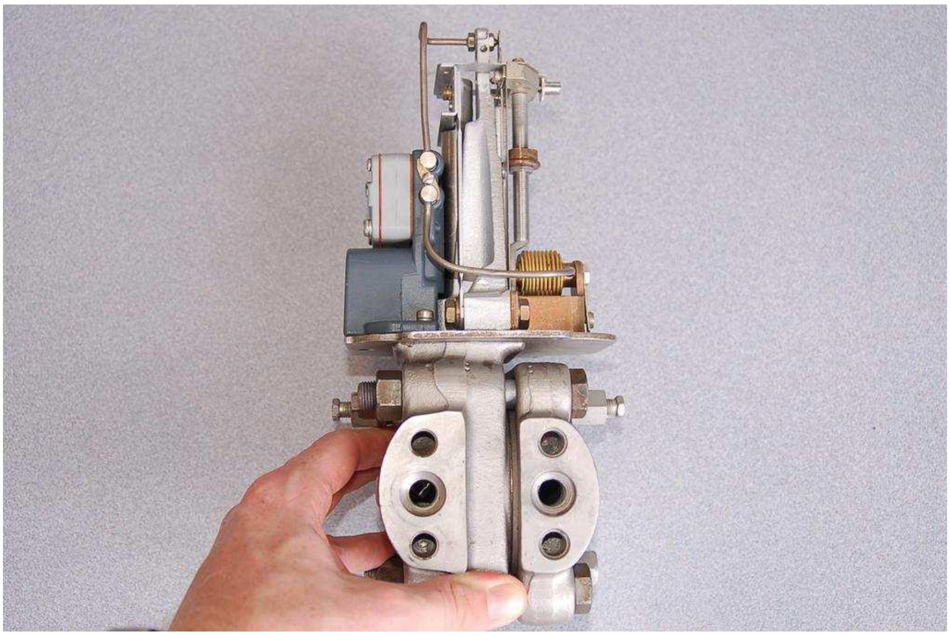
The gain of this Fisher relay was much less than that of the Foxboro relay, since output pressure in the Fisher relay was allowed to act against input pressure by exerting force on a sizable diaphragm. The movable vent seat in the Fisher relay made this design a “non-bleeding” type, meaning it possessed the ability to close both supply and vent valves at the same time, allowing it to hold an output air pressure between saturation limits without bleeding a substantial amount of compressed air to atmosphere through the vent. The Foxboro relay design, by contrast, was a “bleeding type,” whose ball and stem valves could never close simultaneously, and thus would always bleed some compressed air to atmosphere so long as the output pressure remained somewhere between saturation limits.

Pneumatic Instrumentation - Analysis of Practical Pneumatic Instruments

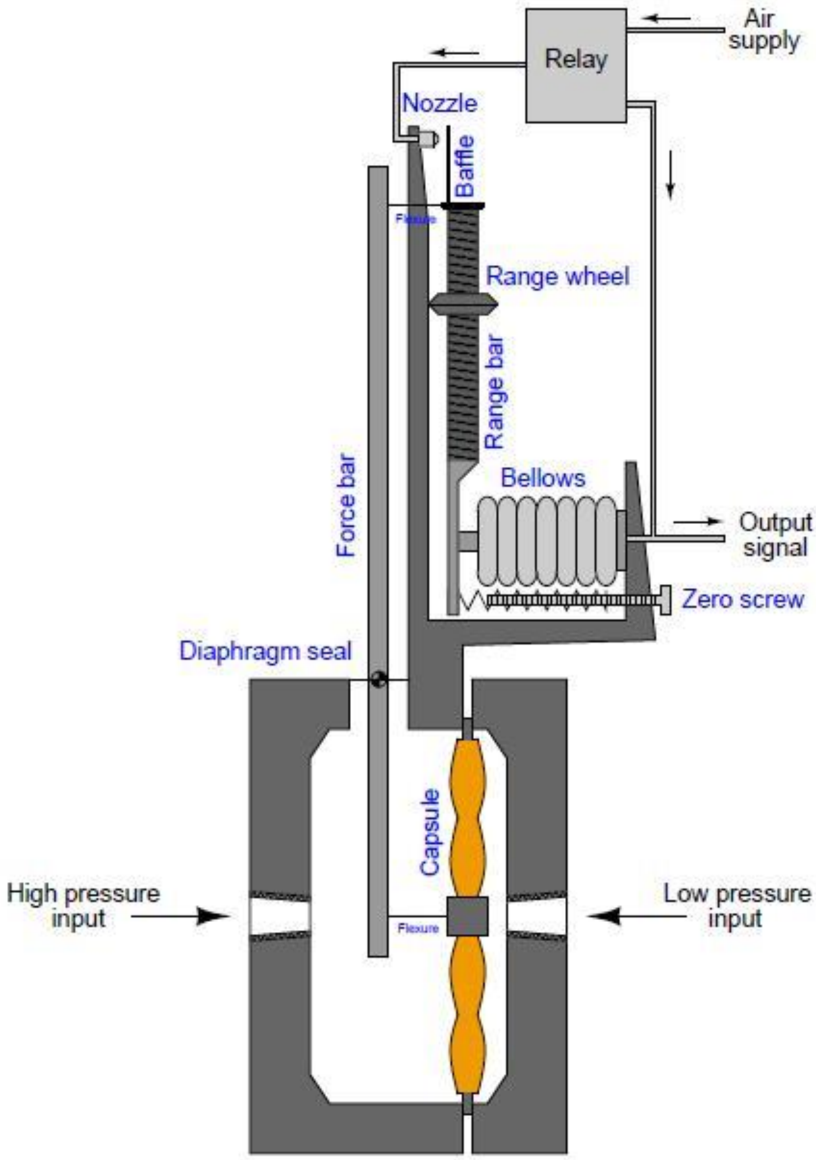
To better understand the design and operation of self-balancing pneumatic mechanisms, it is helpful to examine the workings of some actual instruments. In this section, we will explore three different pneumatic instruments: the Foxboro model 13A differential pressure transmitter, the Foxboro model E69 I/P (electro-pneumatic) transducer, the Fisher model 546 I/P (electro-pneumatic) transducer, and the Fisher-Rosemount model 846 I/P (electro-pneumatic) transducer.

Foxboro model 13A differential pressure transmitter

Perhaps one of the most popular pneumatic industrial instruments ever manufactured is the Foxboro model 13 differential pressure transmitter. A photograph of one with the cover removed is shown here:

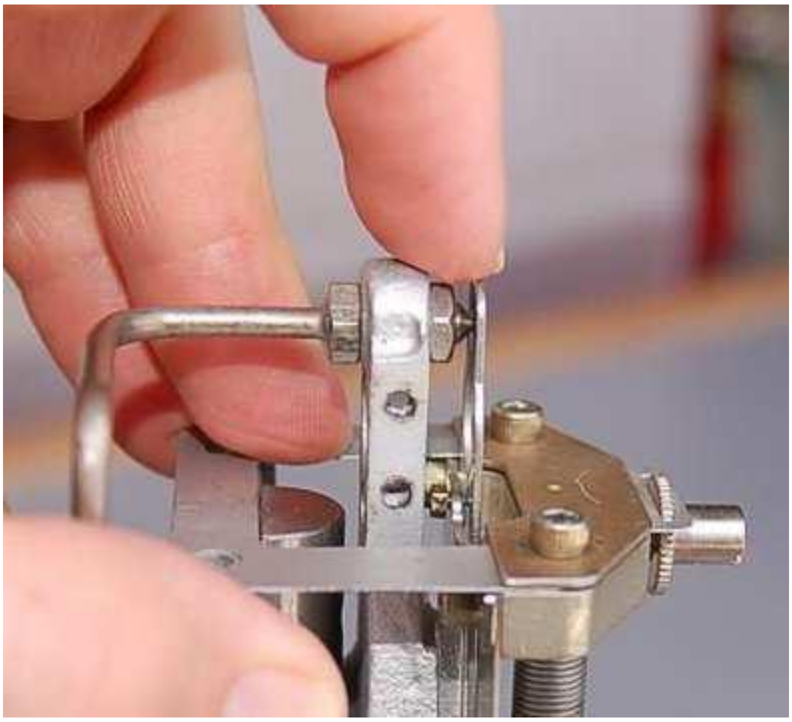


A functional illustration of this instrument identifies its major components:



Part of the reason for this instrument's popularity is the extreme utility of differential pressure transmitters in general. A "DP cell" may be used to measure pressure, vacuum, pressure differential, liquid level, liquid or gas flow, and even liquid density. A reason for this particular differential transmitter's popularity is excellent design: the Foxboro model 13 transmitter is rugged, easy to calibrate, and quite accurate.

Like so many pneumatic instruments, the model 13 transmitter uses the force-balance (more precisely, the moment-balance) principle whereby any shift in position is sensed by a detector (the baffle/nozzle assembly) and immediately corrected through negative feedback to restore equilibrium. As a result, the output air pressure signal becomes an analogue of the differential process fluid pressure sensed by the diaphragm capsule. In the following photograph you can see my index finger pointing to the baffle/nozzle mechanism at the top of the transmitter:

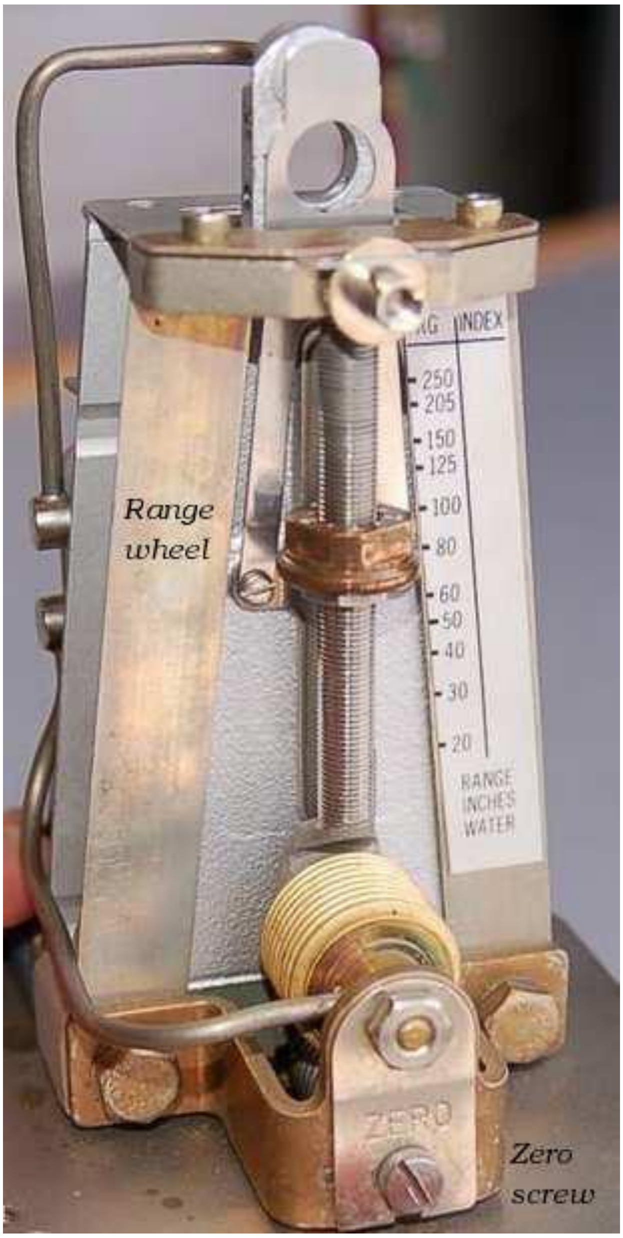


Let’s analyze the behavior of this transmitter step-by-step as it senses an increasing pressure on the “High pressure” input port. As the pressure here increases, the large diaphragm capsule is forced to the right. The same effect would occur if the pressure on the “Low pressure” input port were to decrease. This is a differential pressure transmitter, so what it responds to is changes in pressure difference between the two input ports.

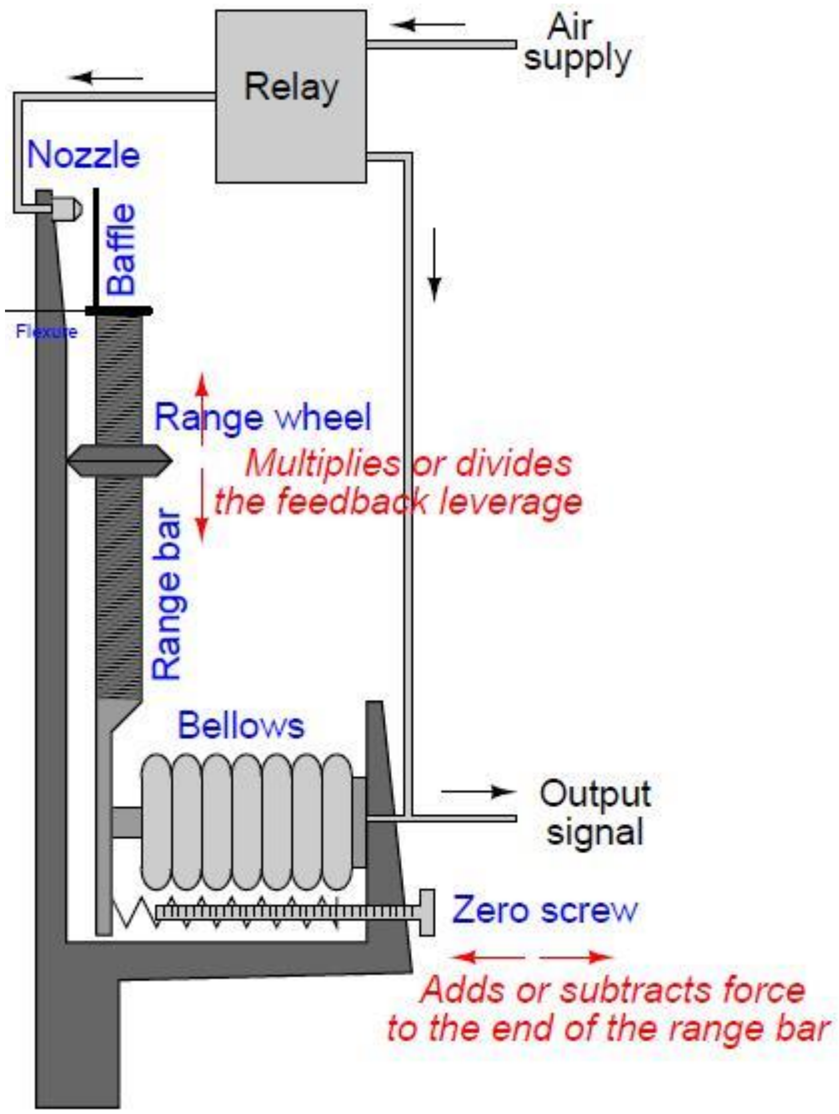
This resultant motion of the capsule tugs on the thin flexure connecting it to the force bar. The force bar pivots at the fulcrum (where the small diaphragm seal is located) in a counter-clockwise rotation, tugging the flexure at the top of the force bar. This motion causes the range bar to also pivot at its fulcrum (the sharp-edged “range wheel”), moving the baffle closer to the nozzle.

As the baffle approaches the nozzle, air flow through the nozzle becomes more restricted, accumulating backpressure in the nozzle. This backpressure increase is greatly amplified in the relay, which sends an increasing air pressure signal both to the output line and to the bellows at the bottom of the range bar. Increasing pneumatic pressure in the bellows causes it to push harder on the bottom of the range bar, counterbalancing the initial motion and returning the range bar (and force bar) to their near-original positions.

Calibration of this instrument is accomplished through two adjustments: the zero screw and the range wheel. The zero screw simply adds tension to the bottom of the range bar, pulling it in such a direction as to collapse the bellows as the zero screw is turned clockwise. This action pushes the baffle closer to the nozzle and tends to increase air pressure to the bellows as the system seeks equilibrium. If a technician turns the range wheel, the lever ratio of the range bar changes, affecting the ratio of force bar force to bellows force. The following photograph shows the range bar and range wheel of the instrument:



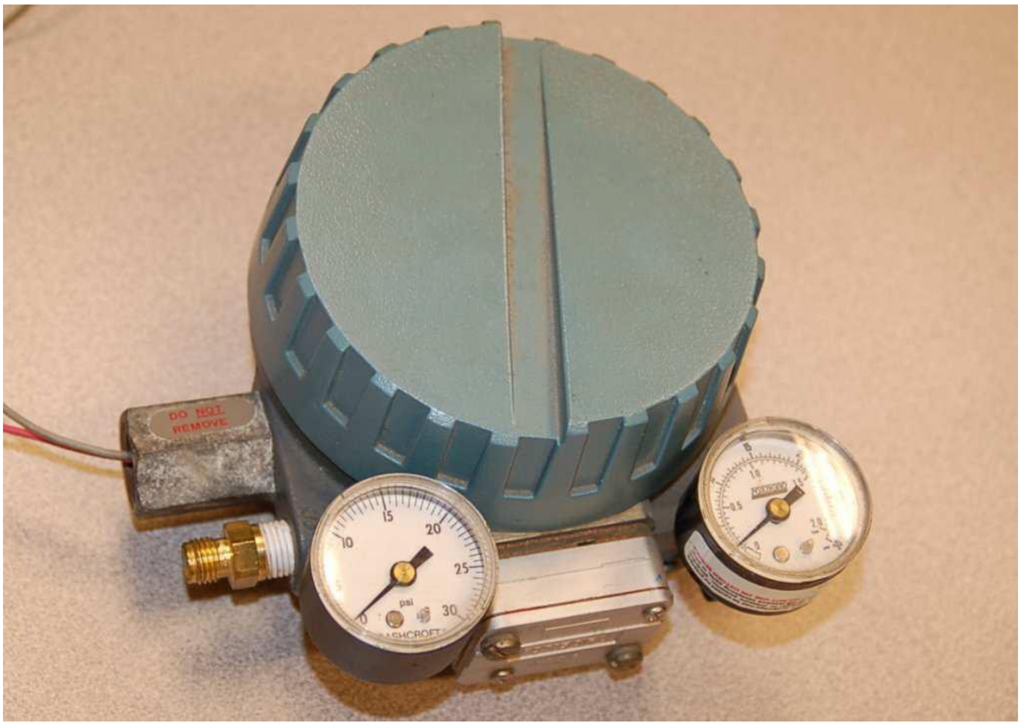
As in all instruments, the zero adjustment works by adding or subtracting a quantity, while the span adjustment works by multiplying or dividing a quantity. In the Foxboro model 13 pneumatic transmitter, the quantity in question is force, since this is a force-balance mechanism. The zero screw adds or subtracts force to the mechanical system by tensioning a spring, while the range wheel multiplies or divides force in the system by changing the mechanical advantage (force ratio) of a lever.



Foxboro model E69 “I/P” electro-pneumatic transducer

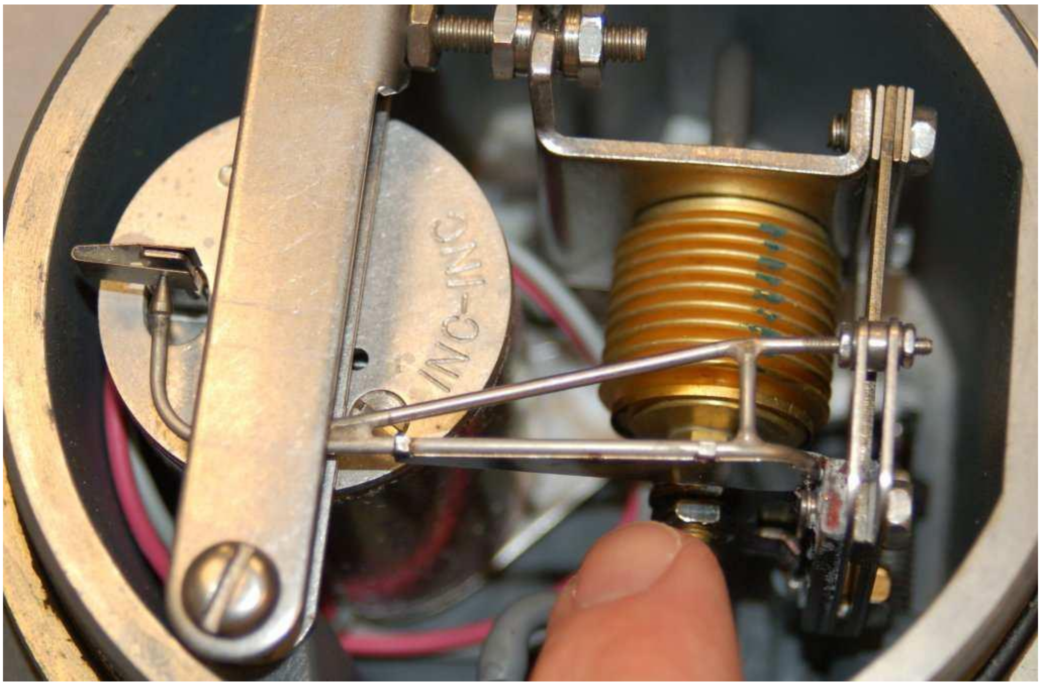
The purpose of any “I/P” transducer is to convert an electrical signal into a corresponding pneumatic signal. In most cases, this means an input of 4-20 mA DC and an output of 3-15 PSI, but alternative ranges do exist.

An example of an I/P transducer manufactured by Foxboro is the model E69, shown here:



Two pressure gauges indicate supply and output pressure, respectively. Wires convey the 4-20 mA electrical signal into the coil unit inside the transducer.

A view with the cover removed shows the balancing mechanism used to generate a pneumatic pressure signal from the electric current input. The baffle/nozzle may be seen at the left of the mechanism, the nozzle located at the end of a bent tube, facing the flat baffle on the surface of the circular coil unit:



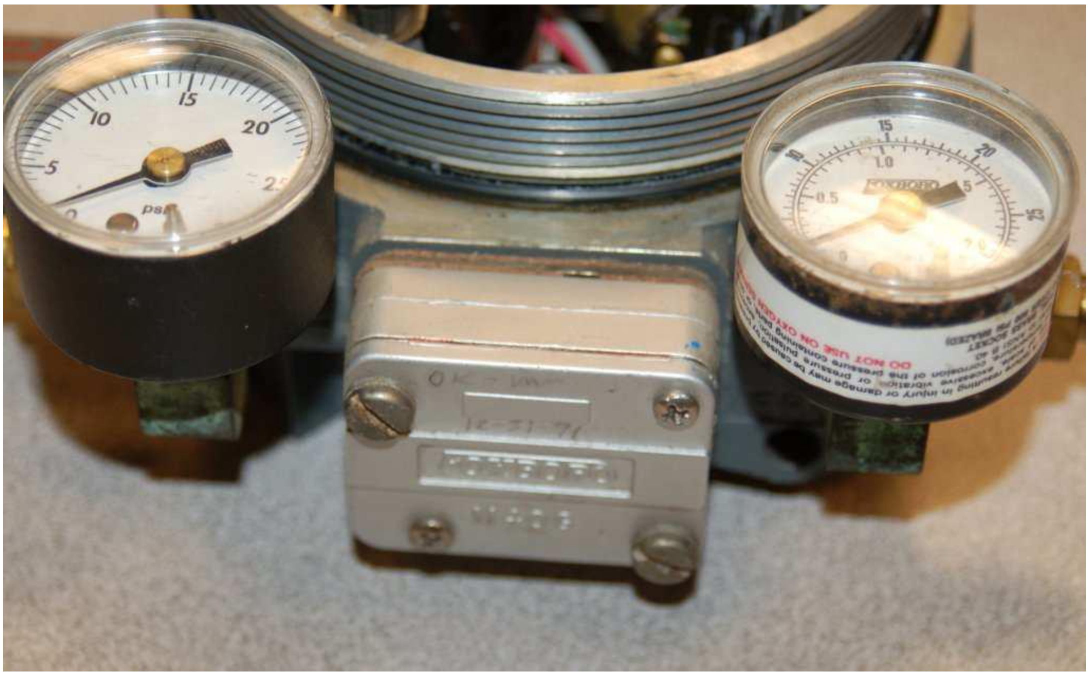
As electric current passes through the coil, it produces a magnetic field which reacts against a permanent magnet's field to generate a torque. This torque causes rotation against the restraint of a spring, with the baffle connected to the rotating assembly. Thus, the baffle moves like the needle of an analog electric meter movement in response to current: the more current through the coil, the more the coil assembly moves (and the baffle moves with it).

The nozzle faces this baffle, so when the baffle begins to move toward the nozzle, backpressure within the nozzle rises. This rising pressure is amplified by the relay, with the output pressure applied to a bellows. As the bellows expands, it draws the nozzle away from the advancing baffle, achieving balance by matching one motion (the baffle's) with another motion (the nozzle's).

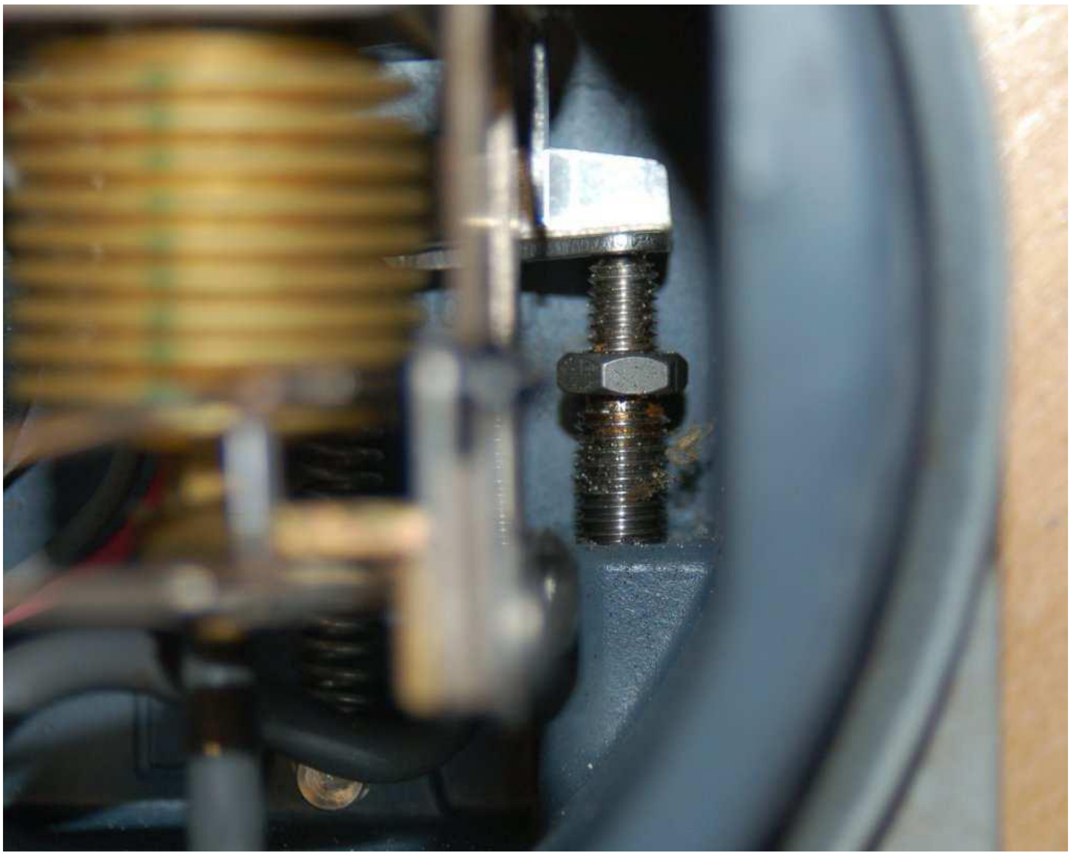
A closer view shows the baffle and nozzle in detail:

Thus, the self-balancing mechanism of the Foxboro model E69 transducer uses the motion-balance principle rather than the force-balance principle as applied in the Foxboro model 13 differential pressure transmitter. Instead of an input force precisely balancing an output force, constraining motion to a negligible degree, this mechanism allows the input freely move, matching that motion with a corresponding output motion to maintain a near-constant baffle/nozzle gap.

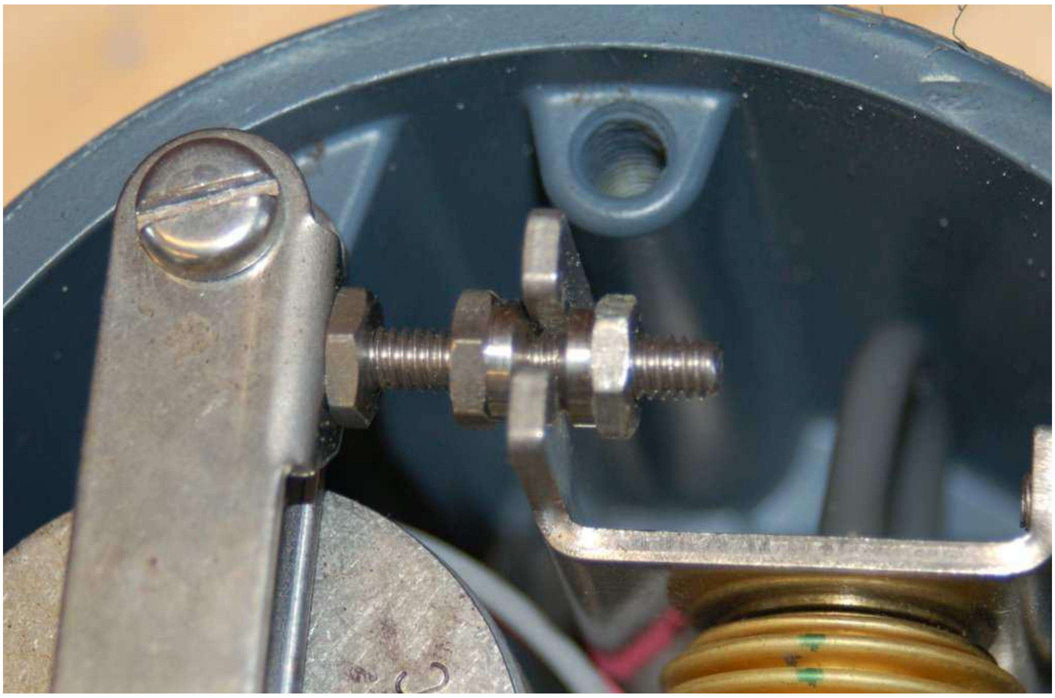
Interestingly the model E69 transducer employs the same pneumatic amplifying relay used in virtually every Foxboro pneumatic instrument:



As in all instruments, the zero adjustment works by adding or subtracting a quantity, while the span adjustment works by multiplying or dividing a quantity. In the Foxboro model E69 transducer, the quantity in question is motion, since this is a motion-balance mechanism. The zero adjustment adds or subtracts motion by offsetting the position of the nozzle closer to or further away from baffle. A close-up photograph of the zero adjustment screw shows it pressing against a tab to rotate the mounting baseplate upon which the coil unit is fixed. Rotating this baseplate add or subtracts angular displacement to/from the baffle's motion:

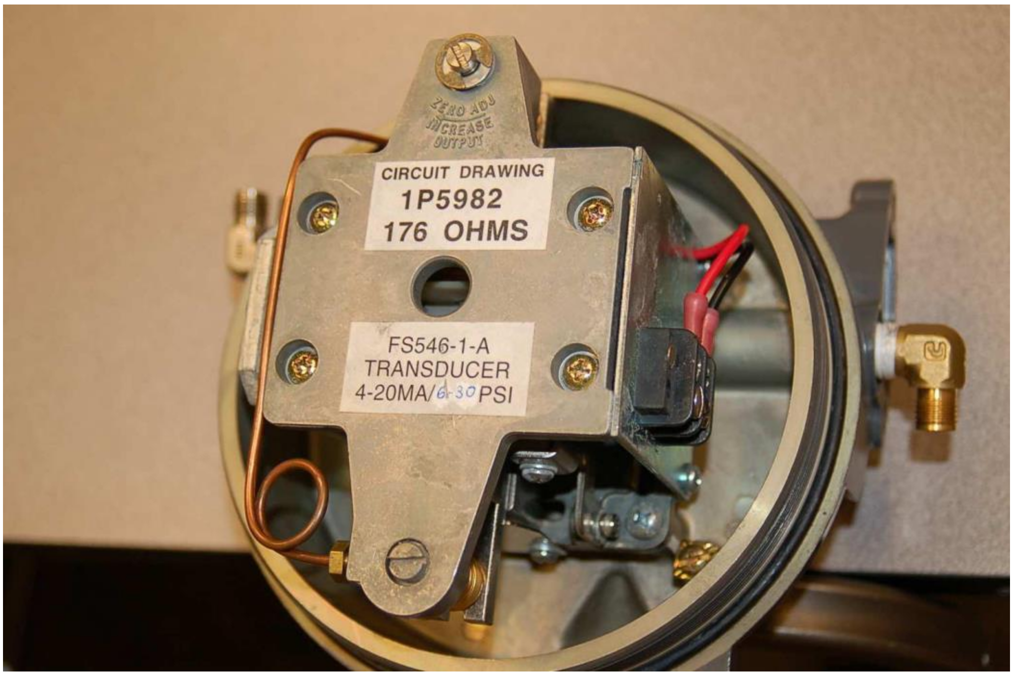


The span adjustment consists of changing the position of the nozzle relative to the baffle's center of rotation, so that a given amount of rotation equates to a different amount of balancing motion required of the nozzle. This adjustment consists of a pair of nuts locking the base of the bellows unit at a fixed distance from the baffle's center of rotation. Changing this distance alters the effective radius of the baffle as it swings around its center, therefore altering the gain (or span) of the motion balance system:

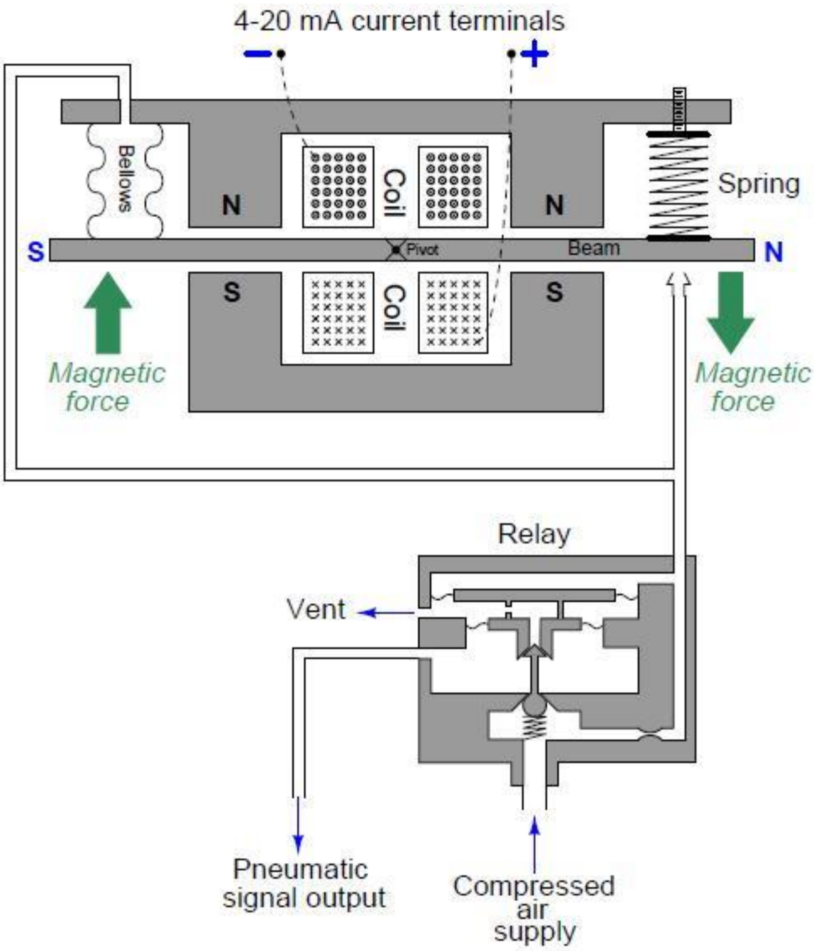


Fisher model 546 "I/P" electro-pneumatic transducer

The Fisher model 546 I/P transducer performs the same signal-conversion function (mA into PSI) as the Foxboro model E69, but it does so differently. The following photograph shows the internal mechanism of the model 546 transducer with its cover removed:



This particular instrument's construction tends to obscure its function, so I will use an illustrative diagram to describe its operation:

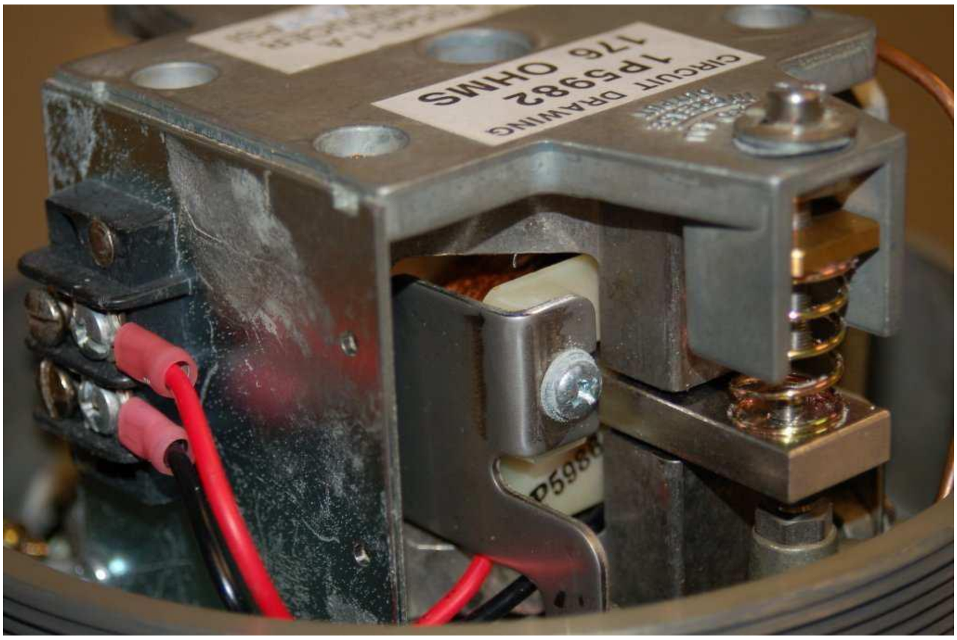


The heart of this mechanism is an iron beam, located between the poles of a permanent magnet assembly, and centered within an electromagnet coil (solenoid). Current passing through the electromagnet coil imparts magnetic poles to the ends of the beam. Following the arrow head/tail convention shown in the coil windings (the dots versus X marks) representing conventional flow vectors pointing out of the page (top) and going into the page (bottom) for the coil wrapped around the beam, the right-hand rule tells us that the beam will magnetize with the right-hand side being "North" and the left-hand side being "South." This will torque the beam clockwise around its pivot point (fulcrum), pushing the right-hand side down toward the nozzle.

Any advance of the beam toward the nozzle will increase nozzle backpressure, which is then fed to the balancing bellows at the other end of the beam. That bellows provides a restoring force to the beam to return it (nearly) to its original position. The phenomenon of an input force being counter-acted by a balancing force to ensure minimum motion is the defining characteristic of a force-balance system. This is the same basic principle applied in the Foxboro model 13 differential pressure transmitter: an input force countered by an output force.

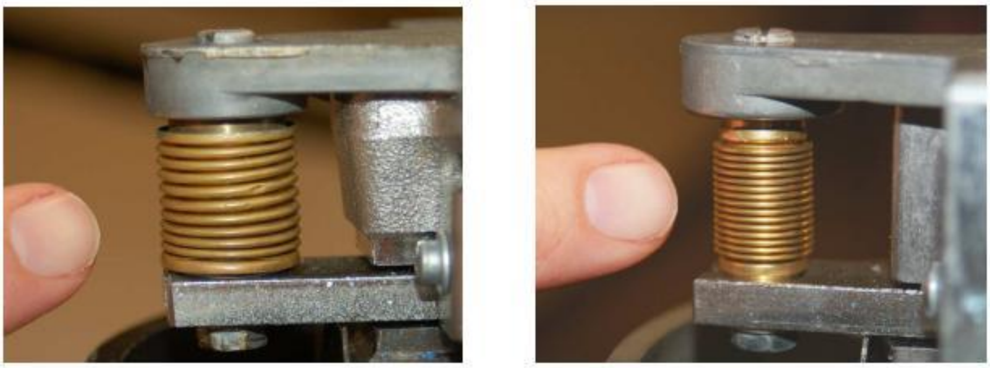
If you examine the diagram carefully, you will notice that this instrument's amplifying relay is not located within the force-balance feedback loop. The nozzle's backpressure is directly fed back to the balancing bellows with no amplification at all. A relay does exist, but its purpose is to provide a modest (approximately 2:1) pressure gain to raise the nozzle backpressure to standard levels (3-15 PSI, or 6-30 PSI).

The next photograph shows the solenoid coil, force beam, and nozzle. If you look closely, you can see the copper-colored windings of the coil buried within the mechanism. The zero-adjustment spring is located above the beam, centered with the nozzle (below the beam):



Fisher manufactured these I/P transducers with two different pneumatic ranges: 3-15 PSI and 6-30 PSI. The mechanical difference between the two models was the size of feedback bellows used in each. In order to achieve the greater pressure range (6-30 PSI), a smaller feedback bellows was used. This may seem backward at first, but it makes perfect sense if you mentally follow the operation of the force-balance mechanism. In order to generate a greater air pressure for a given electric current through the coil, we must place the air pressure at a mechanical disadvantage to force it to rise higher than it ordinarily would in achieving balance. One way to do this is to decrease the effective area of the bellows, so that it takes a greater air pressure to generate the same amount of balancing force on the beam.

A 3-15 PSI bellows (left) is contrasted against a 6-30 PSI bellows (right) in this pair of photographs:



The span adjustment for this I/P transducer is achieved by varying the permanent-magnetic field strength acting against the beam’s electro-magnetic field. Adjustment occurs through the use of a magnetic shunt: an iron plate moved closer to or further away from the permanent magnets, providing an alternate (shunt, or bypass) path for magnetic flux away from the force beam. Moving the shunt further away from the magnets strengthens the magnetic field “seen” by the beam, resulting in a multiplication of force on the beam and therefore a multiplication of output pressure. Moving the shunt closer to the magnets weakens the magnetic field “seen” by the beam, thereby dividing the reaction force and also the output pressure.

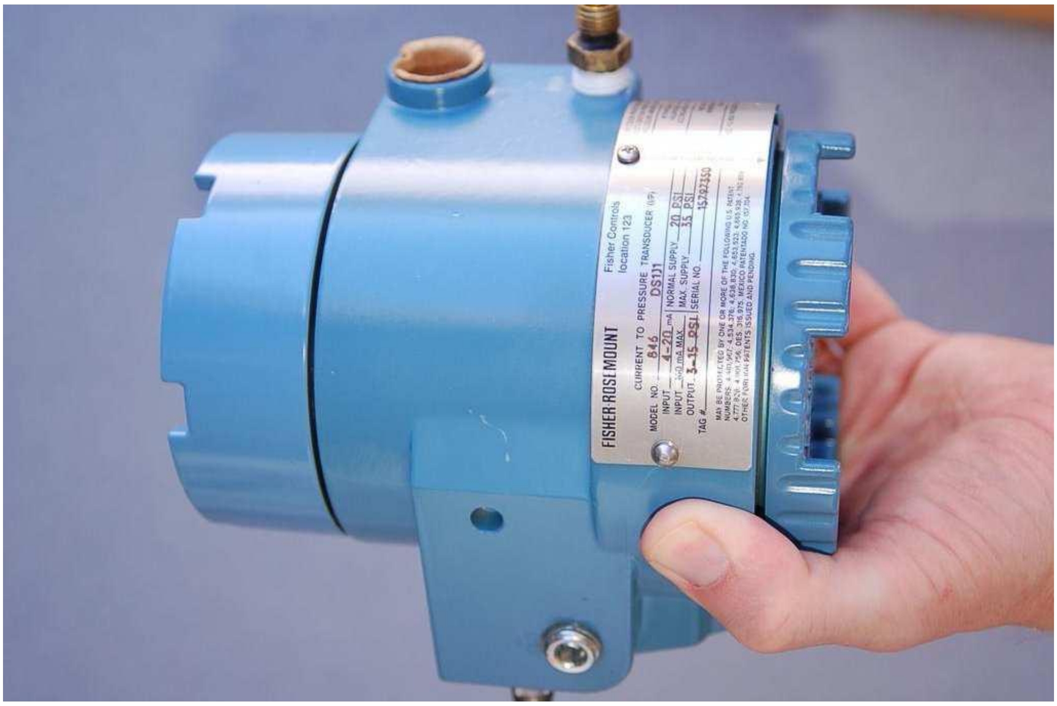
A view of the mechanism’s other side reveals the magnetic shunt plate, complete with an instructional arrow showing the correct direction to turn the adjustment screw to increase output span:

Fisher-Rosemount model 846 "I/P" electro-pneumatic transducer

The Fisher-Rosemount model 846 is a more modern I/P transducer than either the Foxboro model E69 or the Fisher model 546. It employs neither the force-balance nor the motion-balance principle in its operation, which makes it unique to analyze. This I/P unit is also unique in that it features a modular design allowing very convenient replacement of internal components when in service.

This next photograph shows three model 846 I/P transducers attached to a metal panel, below a set of five Rosemount model 1151 pressure transmitters:

A closer photograph reveals the unit in more detail:



When one of the end-covers is unscrewed, the internal workings of the I/P may be removed as a single module. Both the removed module and the housing are shown in this photograph:

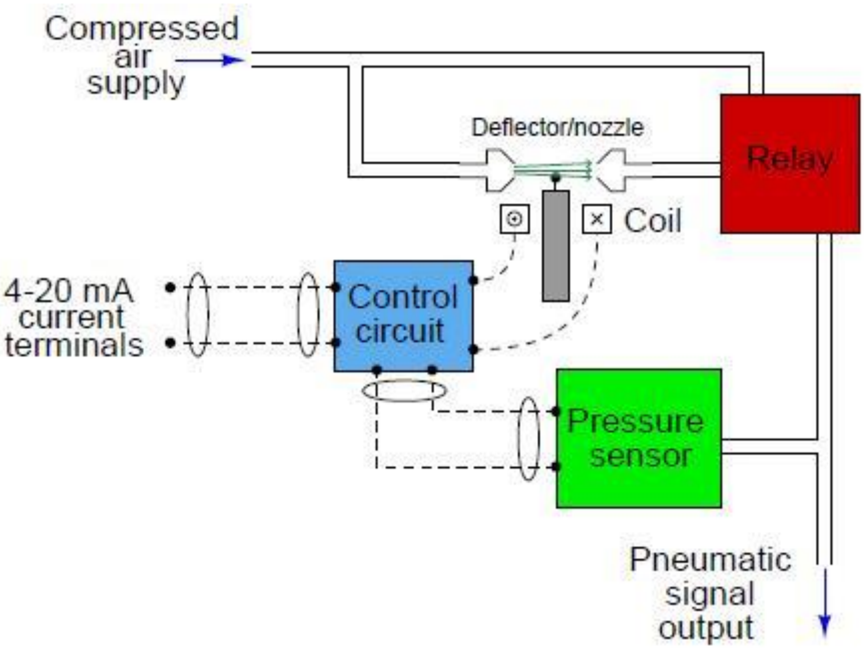
Shown separately, you can see where the module’s current input terminals connect with matching pins in the housing. Even the zero and span adjustment potentiometers on the module circuit board are equipped with Velcro (hook and loop) pads, matching with pads attached to calibration screws on the housing. This simple yet effective mechanical coupling allows screws located on the exterior housing to adjust resistances on the module’s circuit board for zero and span calibration, yet without exposing those delicate potentiometers to ambient weather conditions:

Pneumatic (air) connections are made to the housing through standard 1/4 inch female NPT pipe threads. Compressed air is passed to the module (and from the module back out to the housing) through ports, sealed from each other by O-rings[5] located on the module.

The primary benefit of this modular design is ease of maintenance in the field. If a module fails for any reason, it may be very quickly removed and replaced, with no disconnection and re-connection of signal wires or pneumatic tubes necessary.

[5]It is quite easy to dislodge these small-section, large-diameter O-rings from their respective grooves during re-assembly of the unit. Be very careful when inserting the module back into the housing!

As mentioned before, the feedback mechanism for this particular I/P transducer employs neither the force-balance nor the motion-balance principle. Rather, the negative feedback and balancing of this unit is done electronically rather than mechanically. The following diagram shows how this works:



An electronic pressure sensor continuously monitors the output pressure, with its signal being electronically compared to the input (4-20 mA) signal by the control circuit to check for equivalence. If the output does not match the input, the control circuit drives the deflector motor with more or less current as needed, to deflect the air jet more or less as it exits one nozzle and is intercepted by the other to stimulate the pneumatic amplifying relay. Thus, we see the "balancing" internal to this I/P is done electronically rather than mechanically as it was in the other I/P relays (Foxboro model E69, Fisher model 546) explored in this section.

Electronic components are less likely to drift in their calibration, and are less susceptible to the effects of mechanical vibration and mounting orientation, than mechanical balancing components.