Kalibrering av intrumenter

Kompetansemål:

- utføre arbeid på automatiserte anlegg fagmessig, nøyaktig og i overensstemmelse med krav til helse, miljø og sikkerhet og rutiner for kvalitetssikring og internkontroll
- planlegge, utføre, vurdere kvalitet, sluttkontrollere og dokumentere arbeidet
- tegne, lese og forklare instrumenterte prosessflytskjemaer og bruke annen relevant dokumentasjon for automatiserte anlegg
- montere, konfigurere, kalibrere og idriftsettelse digitale og analoge målesystemer
- måle fysiske størrelser i automatiserte anlegg
- feilsøke og rette feil i automatiserte anlegg
- beskrive ulike vedlikeholdssystemer og -rutiner knyttet til automatiserte anlegg, og anvende et av disse

Læringsmål

- Kunne
- Kunne

Forkunnskaper

-

Teori

afgv.pdf - Instrumentkalibrering

Øvingsoppgaver til leksjon - følger neste side

Innlevering til leksjon - Det er ingen innlevering til leksjonen.

Oppgaver

Oppgave 1

Vi har en analog trykktransmitter med et måleområde på inngangen fra 0 til 400 bar mens utgangen går fra 4-20mA. Etter at en har gjort en 5-punkts opp/ned test har en notert følgende verdier i kalibreringstabellen for as-found:

Kalibreringstabell	
Tilført trykk (bar)	Utgangssignal (mA)
0	4.0
100	8.0
200	12.0
300	16.0
400	20.0
300	16.1
200	12.1
100	8.1
0	4.1

Hvilken type kalibreringsfeil har denne transmitteren?

Oppgave 2

Et nyinstallert pH målesystem ser ikke ut til å måle rett pH verdi på prosessvæsken. Regulatoren som systemet er tilkoblet viser ikke samme verdi som et håndholdt pH-meter om en operatør holder ned i væsken.
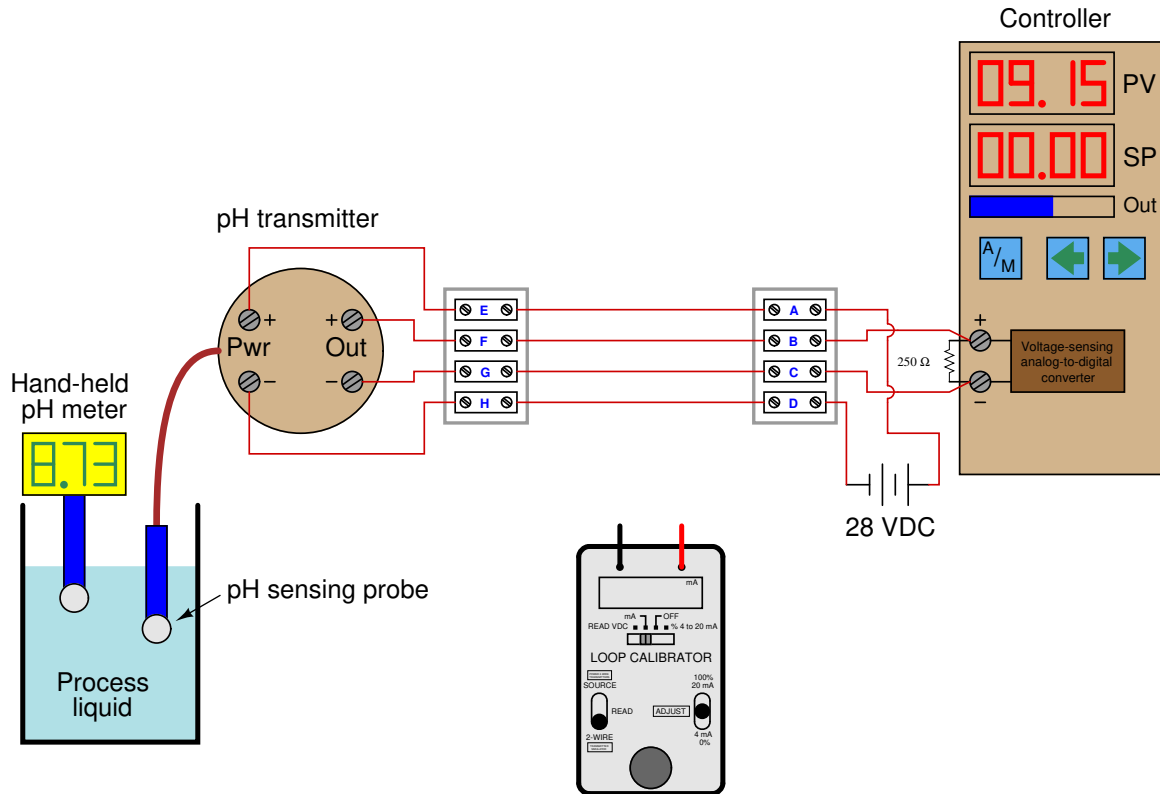
Måleområde til den 4 leder koblede transmitteren skal være 2-12 pH, med et utgangssignal på 4-20mA. En automatiker som har startet feilsøking ved å måle strømmen som transmitteren sender ut med en loopkalibrator. Dette gir et resultat på 15.43 mA.

Ut fra dette skal du finne ut hvor problemet i systemet er. Vis også hvordan du ville koblet loopkalibratoren inn i sløyfen for å gjøre denne målingen.

Suggestions for Socratic discussion

- Review the problem-solving tips listed in Question 0 and apply them to this problem.

- A problem-solving technique useful for making proper connections in pictorial circuit diagrams is to first identify the directions of all DC currents entering and exiting component terminals, as well as the respective voltage polarity marks $(+,-)$ for those terminals, based on your knowledge of each component acting either as an electrical *source* or an electrical *load*. Discuss and compare how these arrows and polarity marks simplify the task of properly connecting wires between components.

- If the technician had no test equipment except for a voltmeter, could a good diagnostic test still be made in this system?

- Identify where you could install a rectifying diode in this circuit to allow convenient measurement of loop current.

Oppgave 3

Vi har en analog trykktransmitter med et måleområde på inngangen fra 0 til 400 bar mens utgangen går fra 4-20mA. Etter at en har gjort en 5-punkts opp/ned test har en notert følgende verdier i kalibreringstabellen for as-found:

Kalibreringstabell	
Tilført trykk (bar)	Utgangssignal (mA)
0	4.0
100	8.0
200	12.0
300	16.0
400	20.0
300	16.1
200	12.1
100	8.1
0	4.1

Hvilken type kalibreringsfeil har denne transmitteren?

Oppgave 4

A pneumatic DP transmitter measures the flow of gasoline through a an orifice plate, using a separate square root extractor relay to characterize the signal so that it may be displayed linearly on the receiver gauge (FI-20):
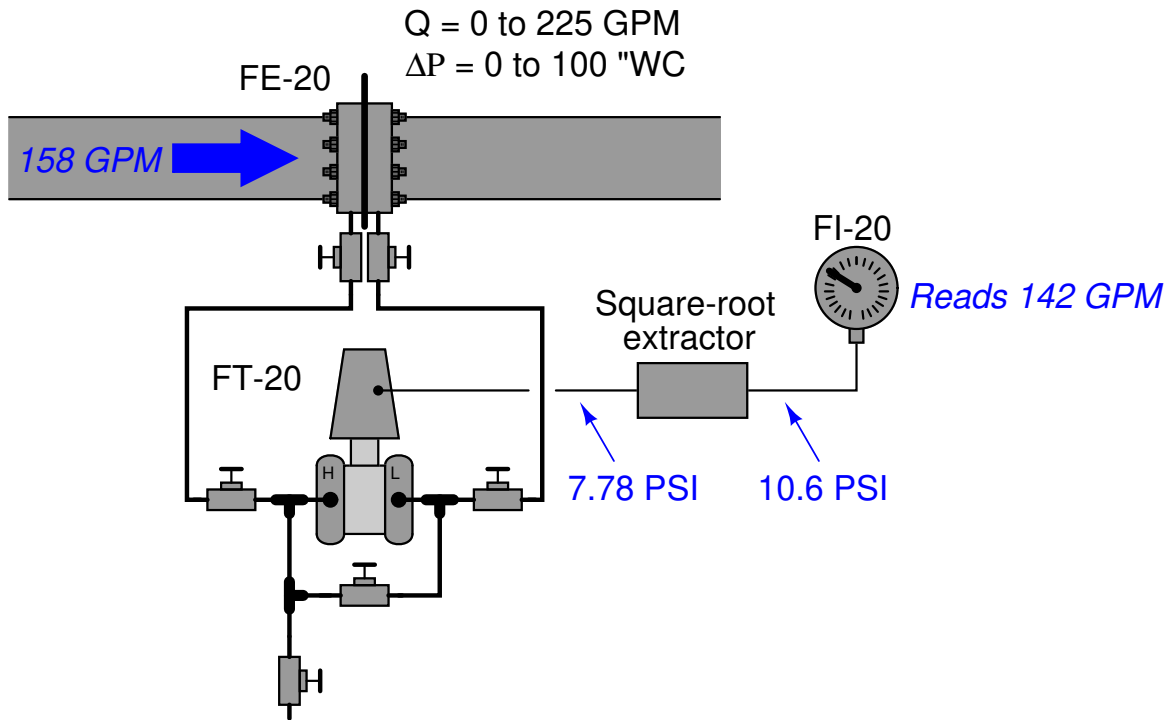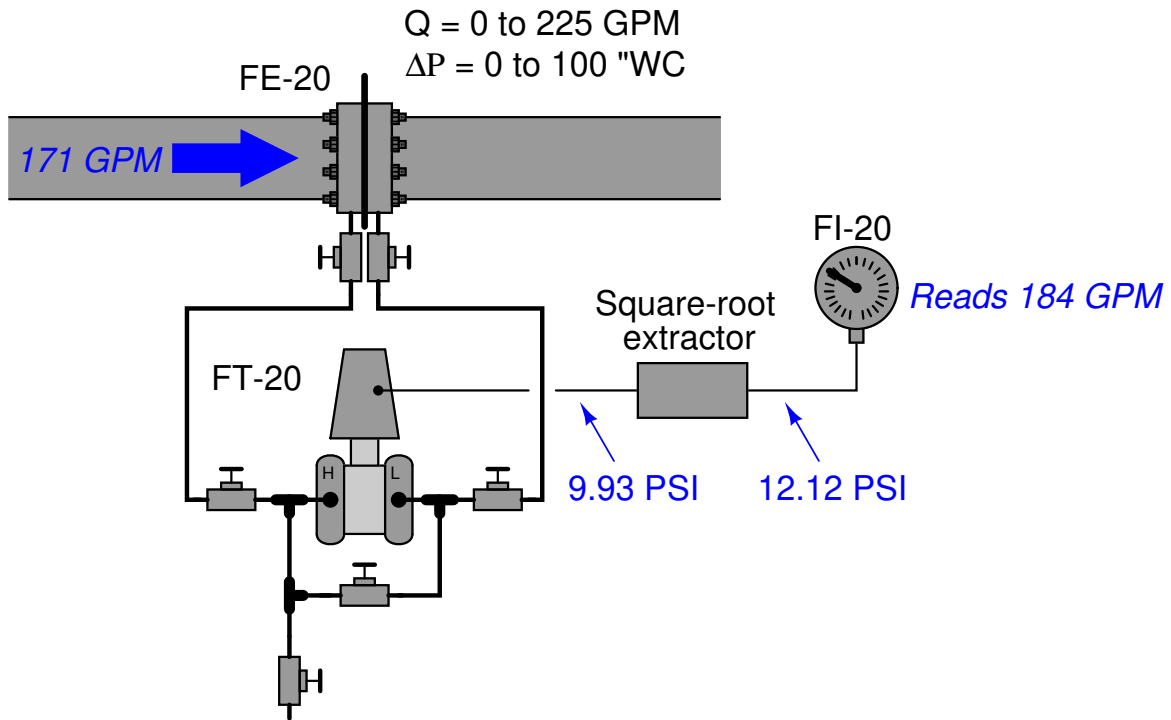

Based on other flow-measuring devices in this process, operations personnel have determined the actual flow rate through this pipe is 158 gallons per minute. FI-20, however, registers a flow of 142 gallons per minute. Based on the data you see in this illustration, determine the location of the calibration error.

file i03440

A pneumatic DP transmitter measures the flow of gasoline through a an orifice plate, using a separate square root extractor relay to characterize the signal so that it may be displayed linearly on the receiver gauge (FI-20):

Q = 0 to 225 GPM
ΔP = 0 to 100 "WC

FE-20

171 GPM

FI-20

Reads 184 GPM

Square-root
extractor

FT-20

H   L

9.93 PSI   12.12 PSI

Based on other flow-measuring devices in this process, operations personnel have determined the actual flow rate through this pipe is 171 gallons per minute. FI-20, however, registers a flow of 184 gallons per minute. Based on the data you see in this illustration, determine the location of the calibration error.
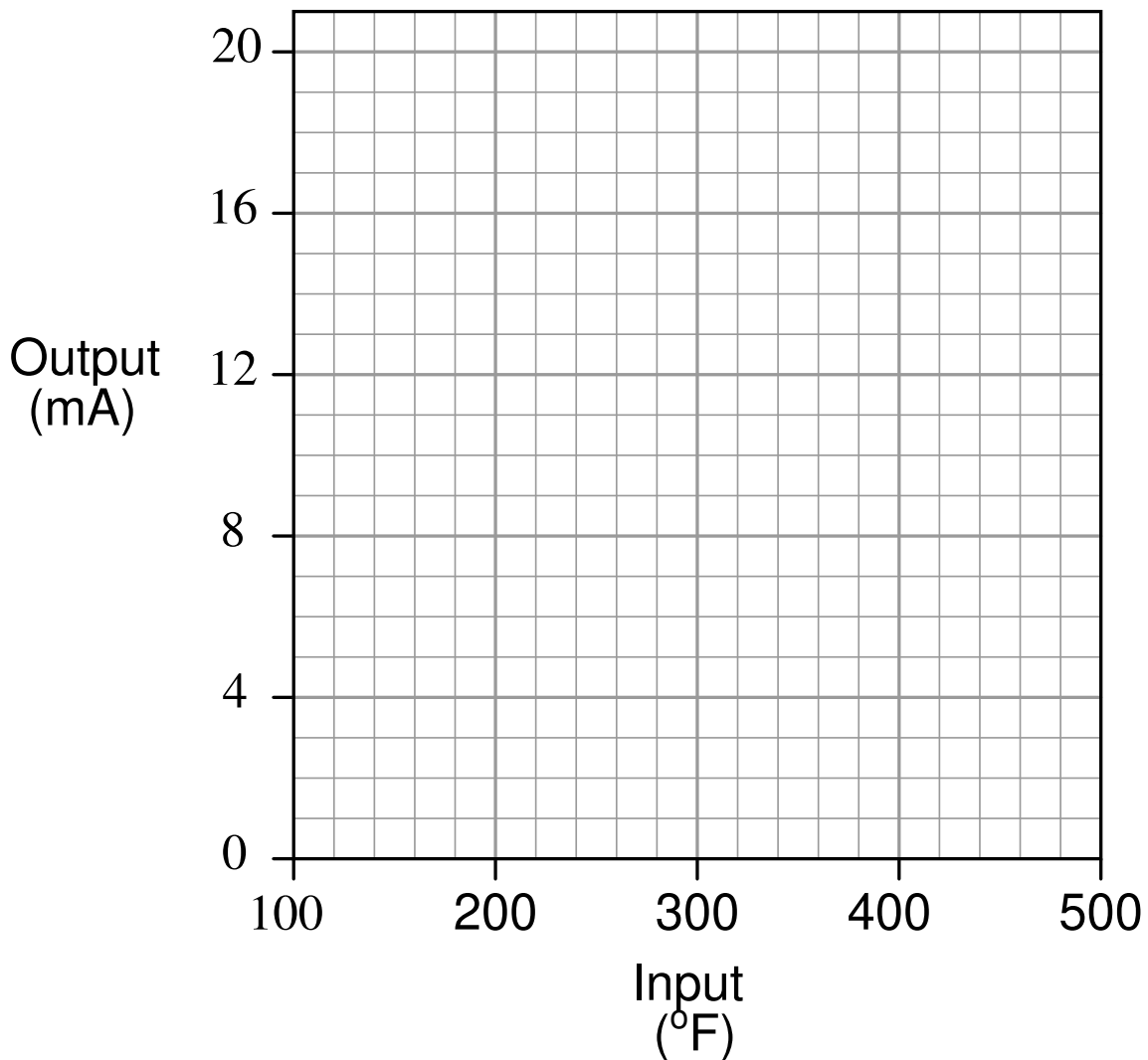
file i03441

Oppgave 6

An electronic temperature transmitter has an input range of 100 to 500 degrees Fahrenheit (type J thermocouple) and an output range of 4 to 20 mA. When subjected to a series of simulated temperatures (5-point up/down test), it responds as such:

Simulated temperature (deg F)	Output signal (mA)
100	4.1
200	8.0
300	11.75
400	16.0
500	20.2
400	16.0
300	11.75
200	8.0
100	4.1

Graph this instrument's ideal transfer function on the graph below, along with its *actual* transfer function graph based on the measured values recorded above. Then, determine what kind of calibration error it has (*zero shift*, *span shift*, *linearity*, and/or *hysteresis*).

Hint: a computer spreadsheet program might be a useful tool in graphing this instrument's response. Feel free to attach a printed copy of a spreadsheet graph instead of hand-sketching one on this page.

file i03489

Oppgave 7

An electronic DP transmitter has an input range of 0 to 100 inches water column and an output range of 4 to 20 mA. When subjected to a series of known pressures (5-point up/down test), it responds as such:

Applied pressure (" WC)	Output signal (mA)
0	3.7
25	7.9
50	12.1
75	16.3
100	20.5
75	16.3
50	12.1
25	7.9
0	3.7

Graph this instrument's ideal transfer function on the graph below, along with its *actual* transfer function graph based on the measured values recorded above. Then, determine what kind of calibration error it has (*zero shift*, *span shift*, *linearity*, and/or *hysteresis*).

Hint: a computer spreadsheet program might be a useful tool in graphing this instrument's response. Feel free to attach a printed copy of a spreadsheet graph instead of hand-sketching one on this page.
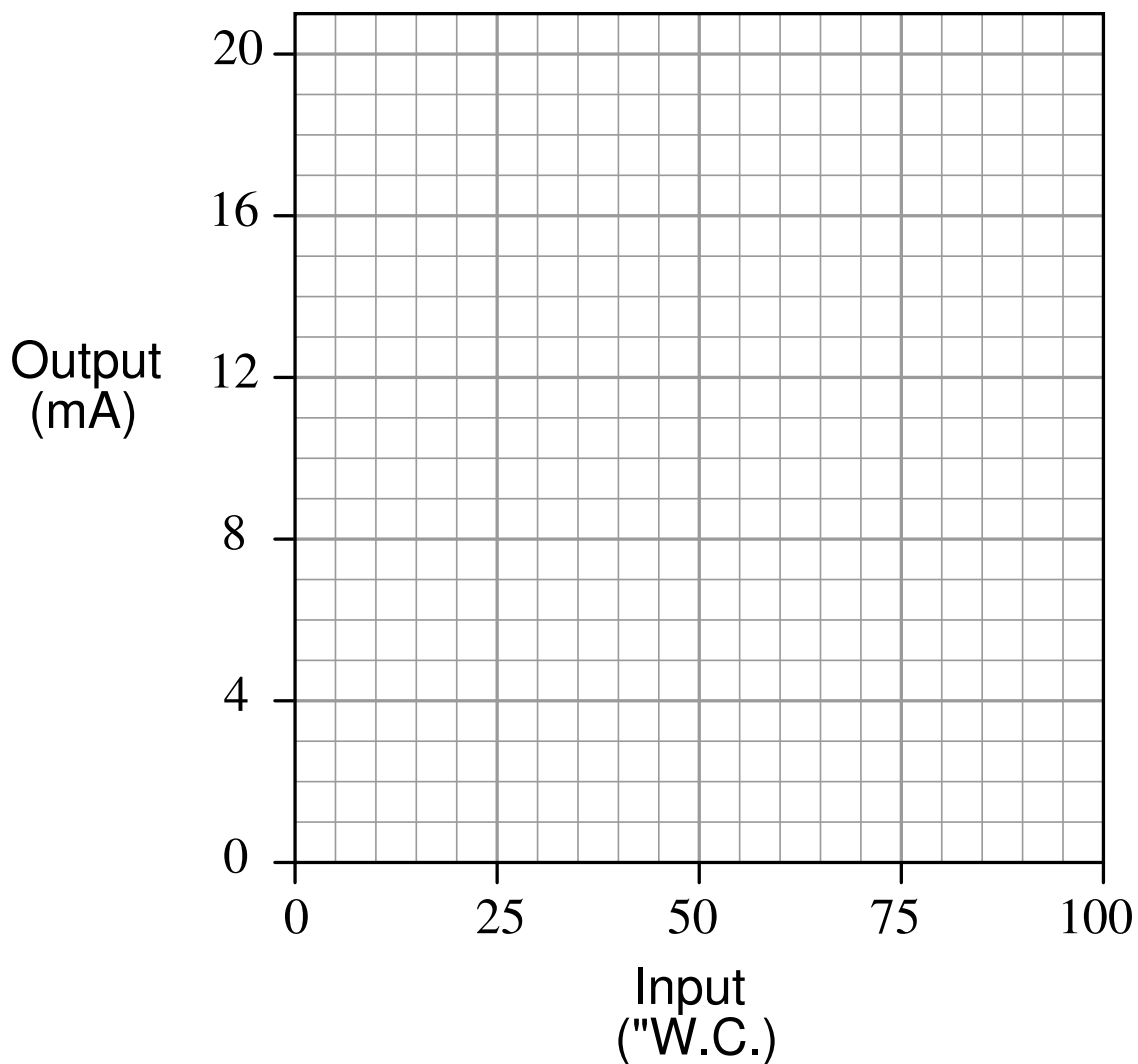
file i03730

Oppgave 8

An electronic DP transmitter has an input range of 0 to 100 inches water column and an output range of 4 to 20 mA. When subjected to a 5-step up-and-down "As-Found" calibration test, it responds as such:

Applied pressure (" WC)	Output signal (mA)
0	4.0
25	8.7
50	12.8
75	16.6
100	20.0
75	16.6
50	12.8
25	8.7
0	4.0

Graph this instrument's ideal transfer function on the graph below, along with its *actual* transfer function graph based on the measured values recorded above. Then, determine what kind of calibration error it has (*zero shift*, *span shift*, and/or *linearity*).
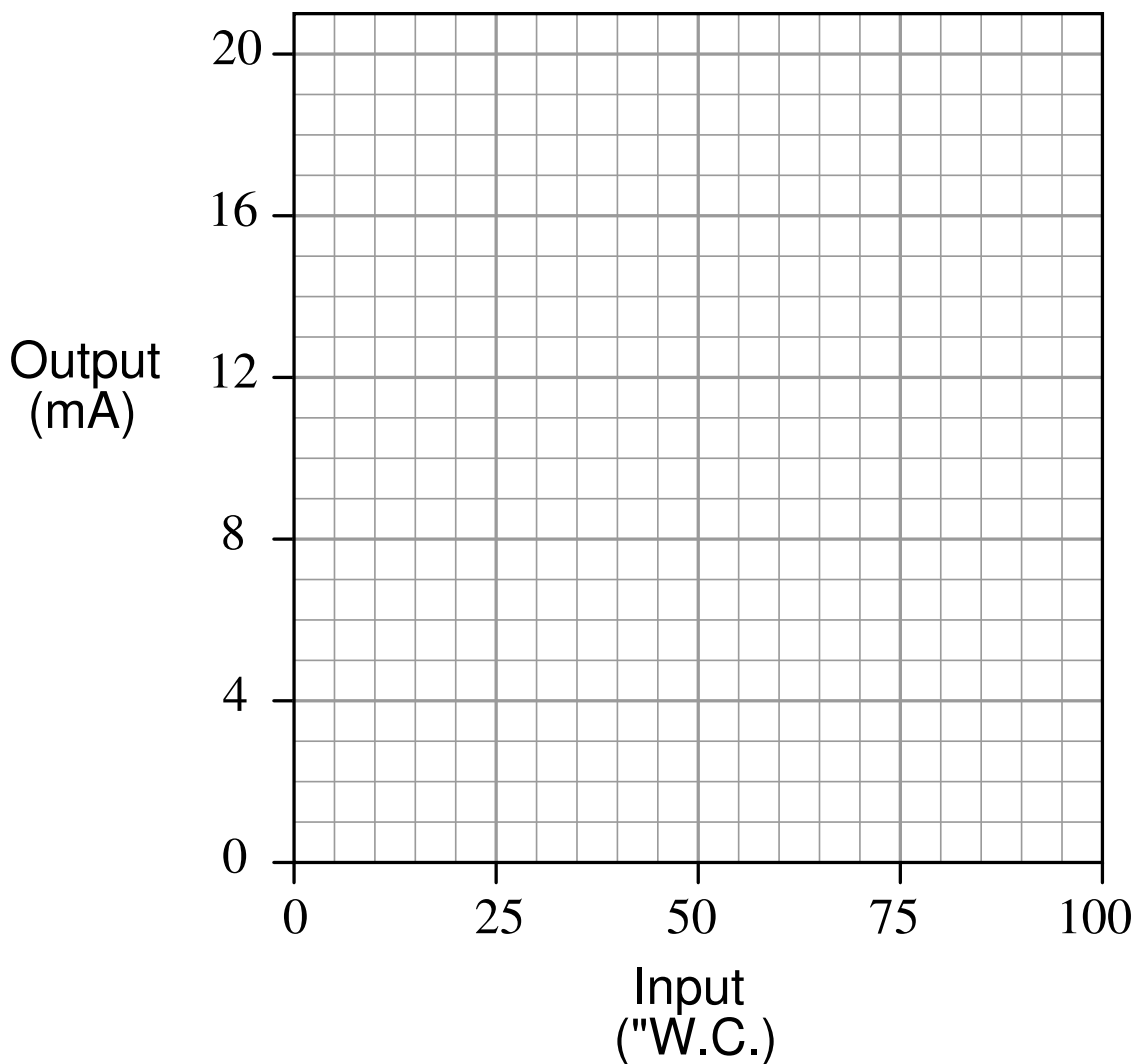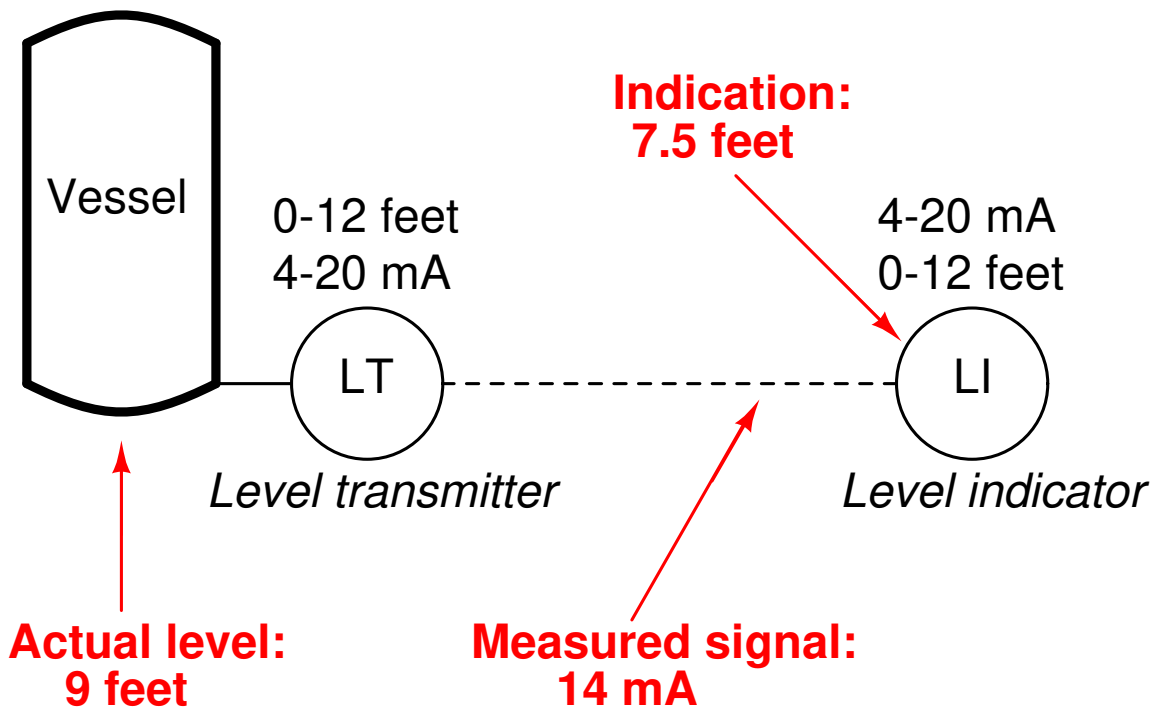
Hint: a computer spreadsheet program might be a useful tool in graphing this instrument's response. Feel free to attach a printed copy of a spreadsheet graph instead of hand-sketching one on this page.

Oppgave 9

A level indicator is registering a liquid level that is falsely low. The operator has hand-gauged the storage vessel with a tape measure and determined the actual level to be 9 feet, but the level indicator (LI) registers 7.5 feet. The calibrated range of the 4-20 mA transmitter is 0 feet to 12 feet. You measure the current signal with your multimeter and find that it is 14 mA. Which instrument is at fault in this system? How do you know?

Indication:
7.5 feet

Vessel

0-12 feet
4-20 mA

4-20 mA
0-12 feet

LT

LI

Level transmitter

Level indicator

Actual level:
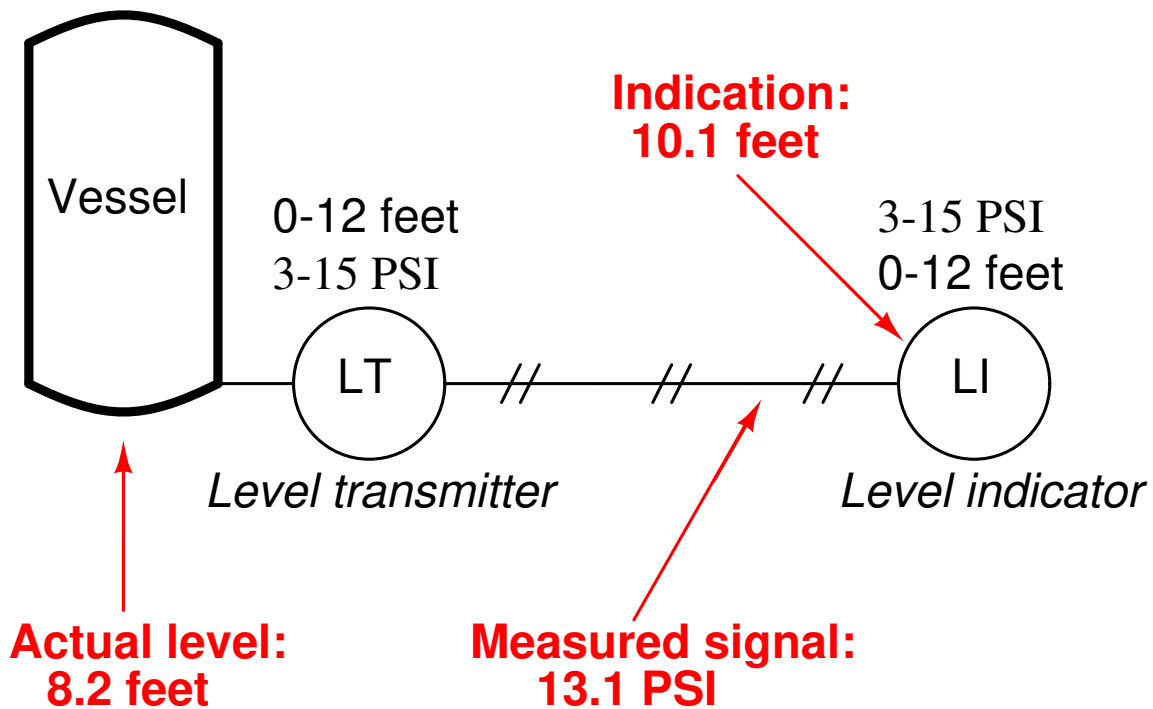**9 feet**

Measured signal:
14 mA

Oppgave 10

A level indicator is registering a liquid level that is falsely high. The operator has hand-gauged the storage vessel with a tape measure and determined the actual level to be 8.2 feet, but the level indicator (LI) registers 10.1 feet. The calibrated range of the 3-15 PSI pneumatic transmitter is 0 feet to 12 feet. You measure the pneumatic pressure signal with a test gauge and find that it is 13.1 PSI. Which instrument is at fault in this system? How do you know?

Indication:
10.1 feet

Vessel

0-12 feet
3-15 PSI

3-15 PSI
0-12 feet

LT

LI

Level transmitter

Level indicator

Actual level:
**8.2 feet**

Measured signal:
13.1 PSI

Furthermore, identify whether the fault is a *zero shift*, a *span shift*, a problem with *linearity*, *hysteresis*, or whether it is impossible to determine from the information we have.

file i02961

Oppgave 11

Sketch the necessary connecting tubes and wires to calibrate a DP transmitter to a low pressure range (somewhere in the range of a few inches of water), using a hand (bicycle-style) air pump as the pressure source and a U-tube manometer as a pressure standard. As pressure increases, the transmitter's output signal should increase as well:

Manometer

Tank

Hand pump

Transmitter under test

24 VDC source

file i00022
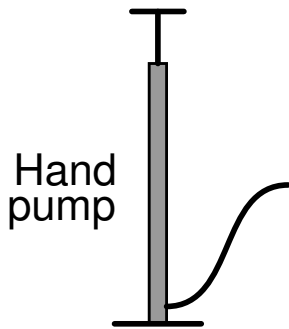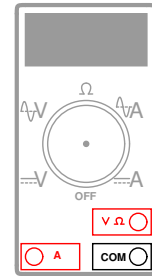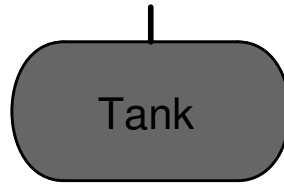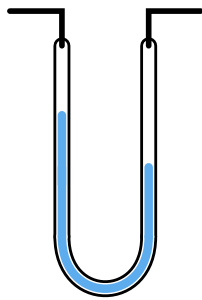
Oppgave 12

One challenge technicians face when calibrating low-pressure instruments is how to generate very low air pressures to simulate different low-pressure conditions for the pressure instrument under test. Measuring low pressures is no problem at all: very simple manometers will do the job quite nicely. M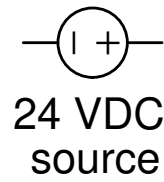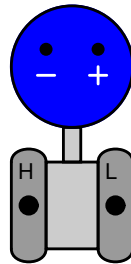ost mechanical air compressors, however, generate pressures far exceeding the range of most manometers. Though it is possible to purchase precision pressure regulators for reducing such large pressures down to a level measurable by a manometer, these devices are expensive.

A simple way to "divide" the pressure output of a standard pressure regulator from a few PSI to a few inches of water is to use a pair of small valves (preferably needle valves allowing for precise adjustment) to throttle the flow of compressed air and vent the regulator's output to atmosphere, then tap between those valves to obtain a reduced pressure:
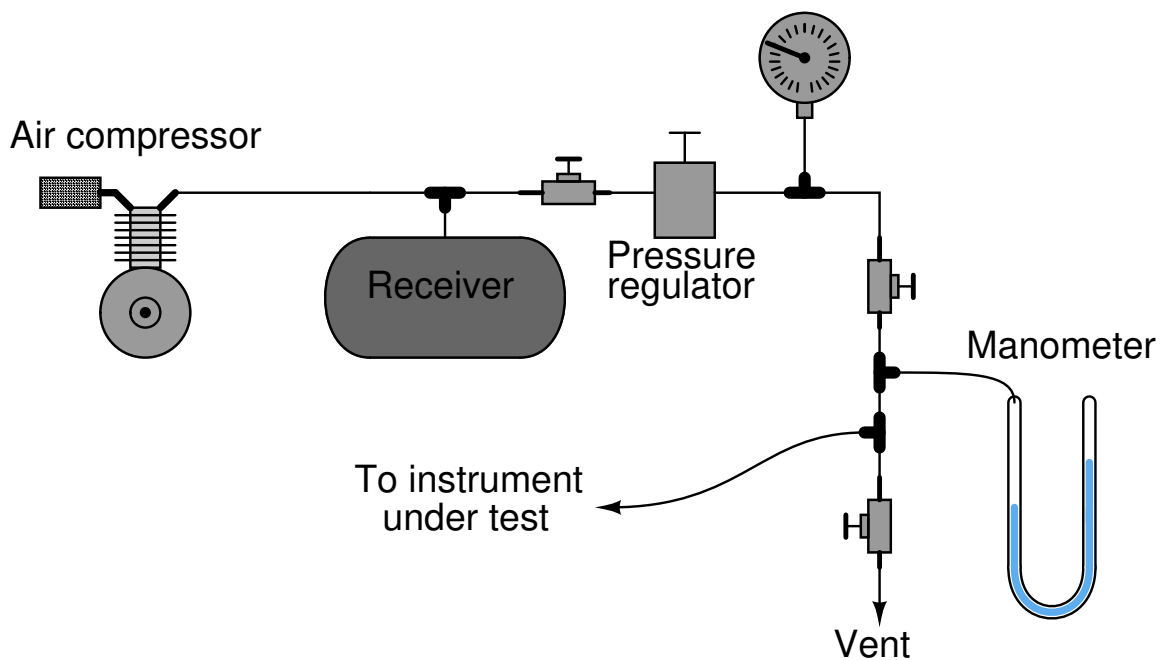
Complete the following schematic diagram showing an electrical model for this pneumatic system, and then explain how it works:

file i00287
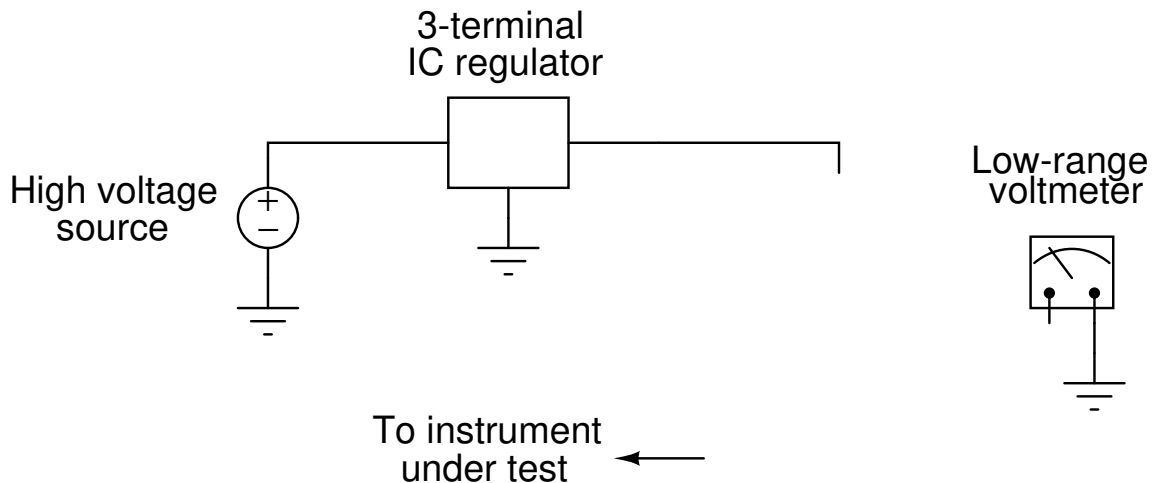
Oppgave 13

A common form of measurement error in instruments is called *hysteresis*. A very similar type of measurement error is called *deadband*. Describe what these errors are, and differentiate between the two.

file i00091

Oppgave 14

This hydrostatic liquid level transmitter system has been equipped with *standpipes* and extra hand valves to enable "wet calibration" of the transmitter:
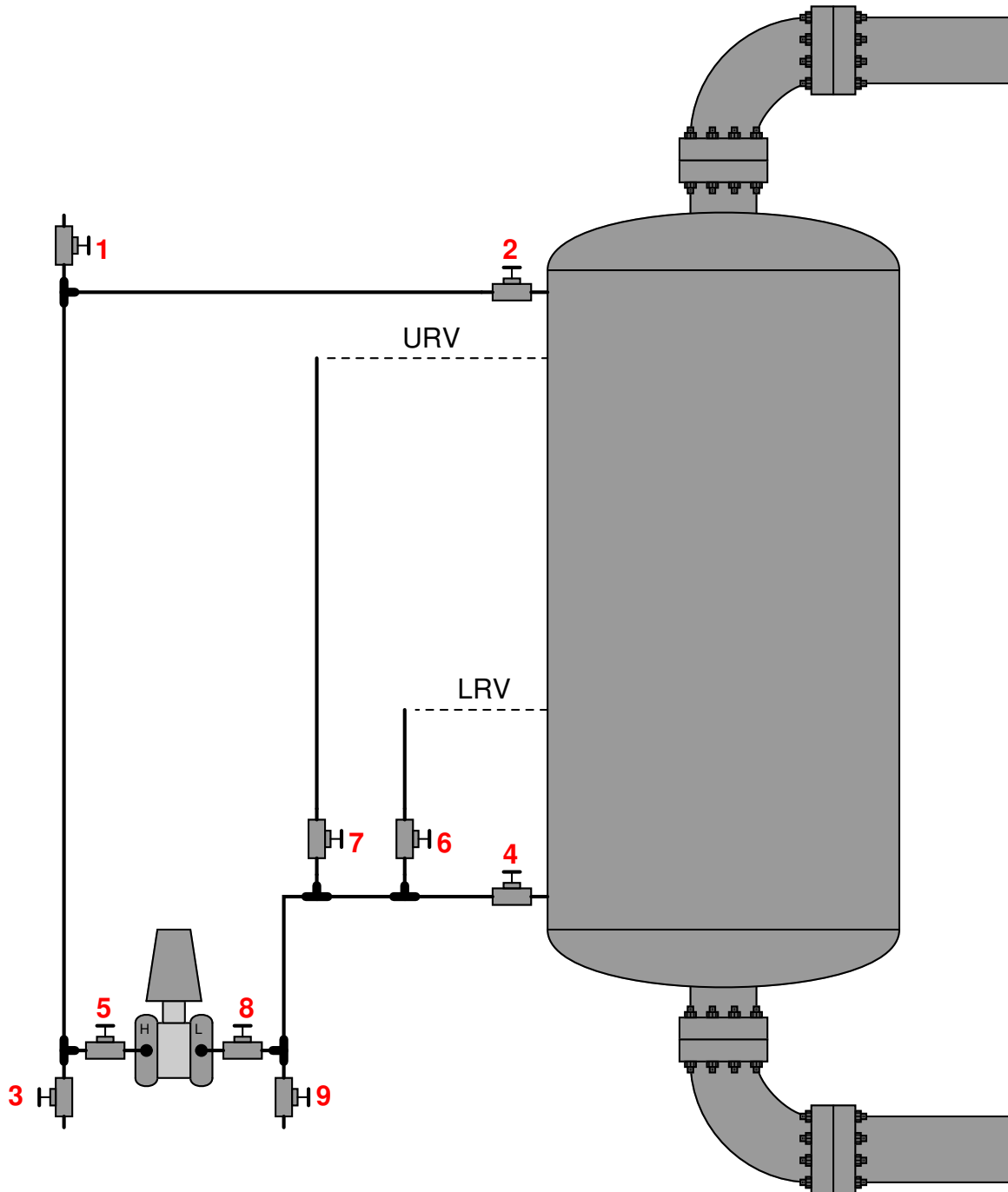
First, identify the proper position (*open* or *shut*) for each hand valve when the transmitter is in regular operation.

Next, specify a procedure to apply an LRV "test pressure" to the transmitter using the valves and standpipe(s).

file i01016

Oppgave 15

An instrument technician working for a pharmaceutical processing company is given the task of calibrating a temperature recording device used to display and log the temperature of a critical batch vessel used to grow cultures of bacteria. After removing the instrument from the vessel and bringing it to a workbench in the calibration lab, the technician connects it to a calibration standard which has the ability to simulate a wide range of temperatures. This way, she will be able to test how the device responds to different temperatures and make adjustments if necessary.

Before making any adjustments, though, the technician first inputs the full range of temperatures to this instrument to see how it responds in its present condition. Then, the instrument indications are recorded as *As-Found* data. Only after this step is taken does the technician make corrections to the instrument's calibration. Then, the instrument is put through one more full-range test and the indications recorded as *As-Left* data.

Explain why it is important that the technician make note of both "As-Found" and "As-Left" data? Why not just immediately make adjustments as soon as an error is detected? Why record any of this data at all? Try to think of a practical scenario where this might matter.

file i00082

Oppgave 16

Analog electronic process transmitters typically have only two calibration adjustments: one for *zero* and another for *span*. Occasionally you may find an analog electronic transmitter with a third adjustment: one for *linearity*.

Modern "smart" process transmitters have more components in need of adjustment. A block diagram of a typical smart pressure transmitter shows this very clearly:
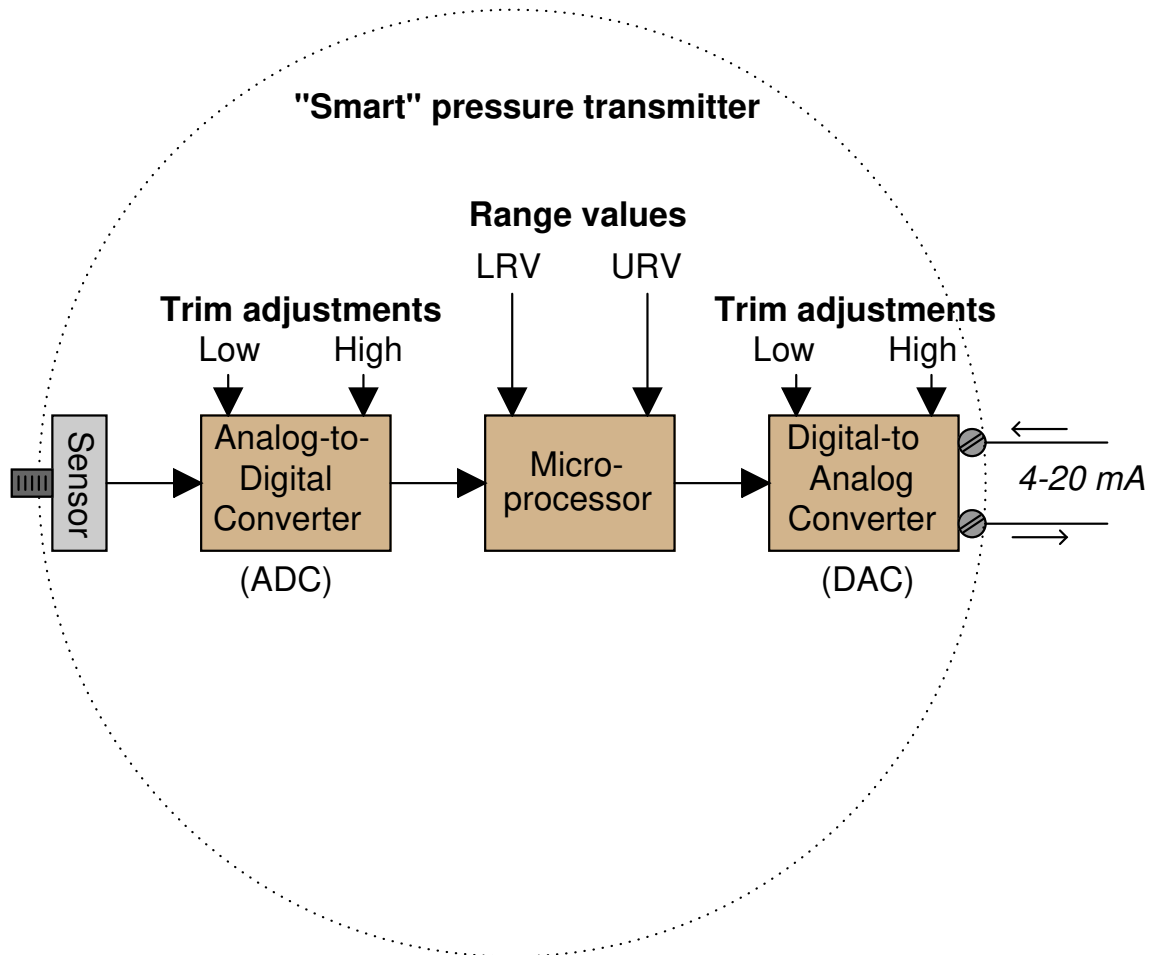
The purpose of the analog-to-digital converter (ADC) is to translate the pressure sensor's electrical output signal into a digital number the microprocessor can understand. Likewise, the purpose of the digital-to-analog converter (DAC) is to translate the digital output of the microprocessor into a 4 to 20 mA DC current signal representing measured pressure. The procedure of calibrating the ADC is called a *sensor trim*, while the process of calibrating the DAC is called an *output trim*.

Explain the importance of performing both a sensor trim and an output trim whenever calibrating a "smart" transmitter. In other words, explain why it is not enough to simply program LRV and URV values into the microprocessor (e.g. LRV = 0 PSI ; URV = 30 PSI) and declare the job finished.

Furthermore, explain what external calibration equipment must be connected to the transmitter to complete a sensor trim procedure, and also what external calibration equipment must be connected in order to complete an output trim procedure.

file i00090

Oppgave 17

A "smart" (digital) DP pressure transmitter is removed from service and taken to a calibration bench for testing. A technician connects a precision pressure gauge and air source to the transmitter's high port while monitoring the 4-20 mA output signal using a DMM:
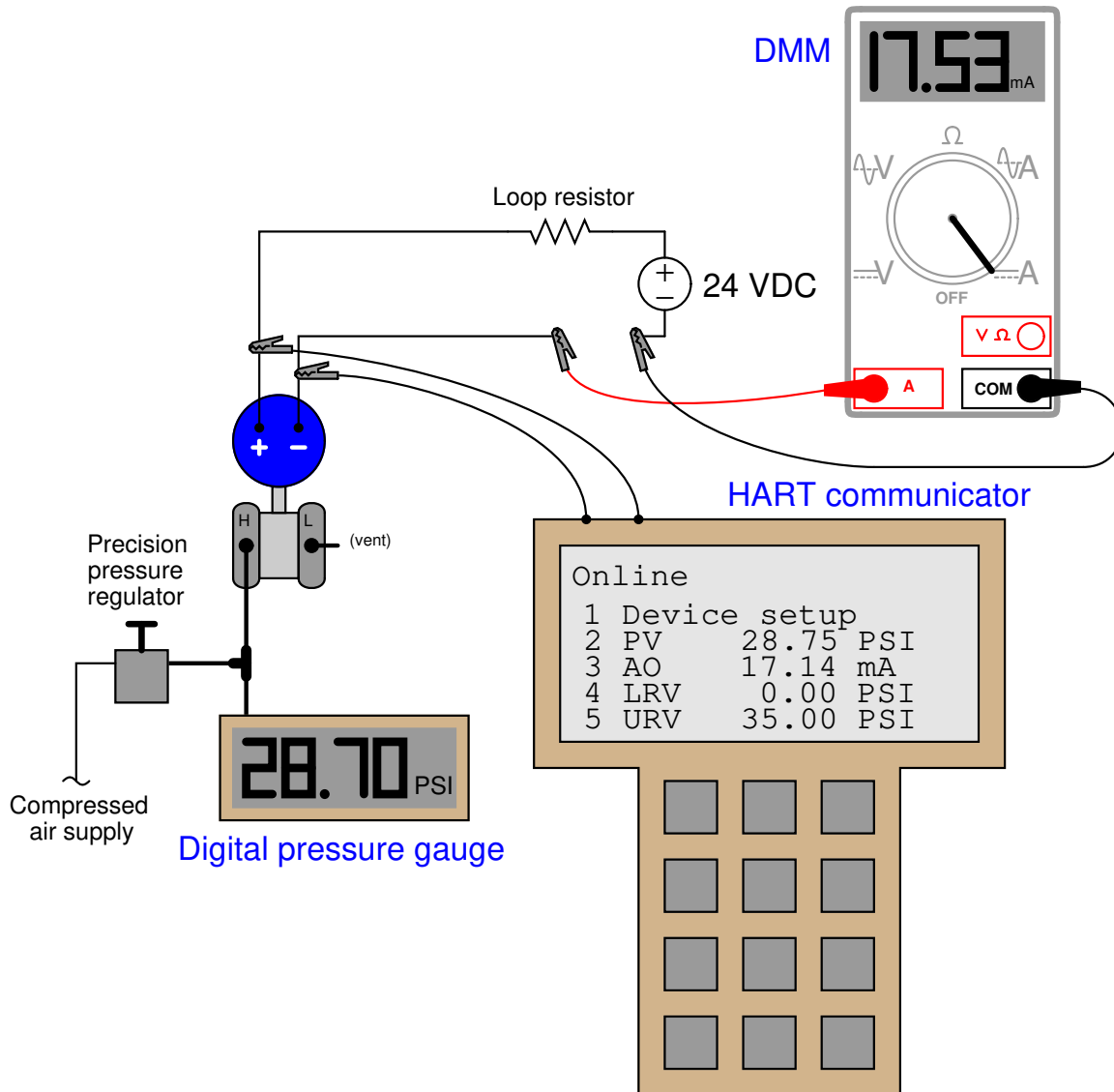
Calculate the amount of *sensor trim* error as well as the amount of *output trim* error, both expressed in percent of span. Also, explain why the HART communicator is necessary to be able to separately calculate these error values.

Suggestions for Socratic discussion

- What other possible sources of error besides the transmitter could account for these discrepancies?

- Suppose another instrument technician suggests to you that a problem within the precision air pressure regulator might account for some (or all!) of the calibration error seen in the data, and that we should replace the regulator with another. How would you respond to this suggestion?

- Suppose another instrument technician suggests to you that a problem within the loop resistor might account for some (or all!) of the calibration error seen in the data, and that we should replace the resistor with another. How would you respond to this suggestion?

- Does the HART communicator need to be NIST traceable? Why or why not?

file i02033

Oppgave 18

A "smart" DP transmitter and orifice plate were recently installed to measure flow through a pipe. The orifice plate range is 0 to 150 inches WC at 0 to 1000 gallons per minute:

0 to 1000 GPM
0 to 150 "WC

To DCS

HART communicator

```
Online

1 Device setup
2 PV      35.81 inH2O
3 AO      11.82 mA
4 LRV     0.000 inH2O
5 URV   150.00 inH2O
```
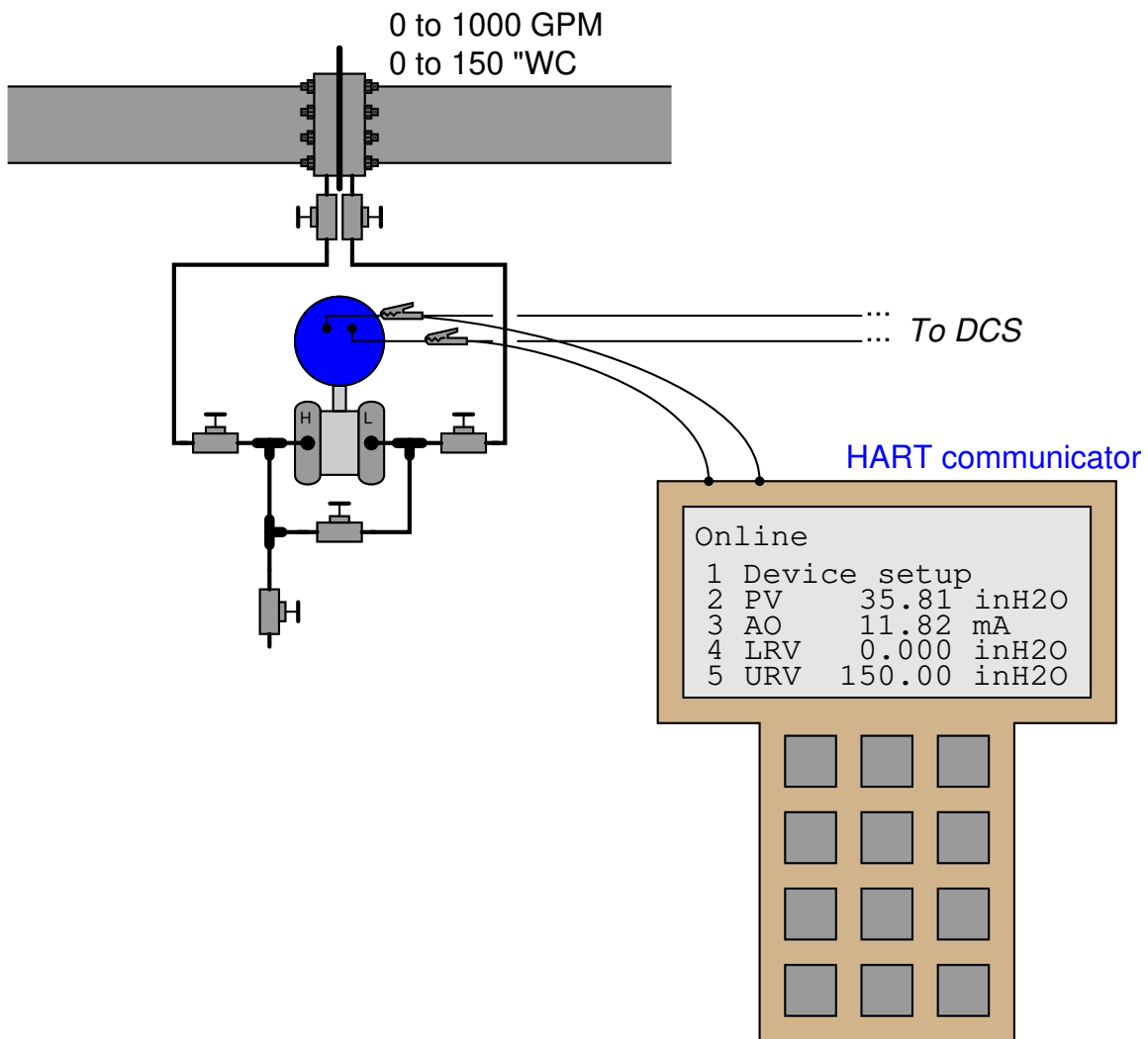
Operations personnel register a flow rate of 699 gallons per minute on the display of their DCS, which they believe to be too much. Based on what you see here, do you think there is a problem, or is this new system working as it should?
file i03428

Oppgave 19

A "smart" DP transmitter with built-in square root characterization is used to measure flow through a pipe. The orifice plate range is 0 to 150 inches WC at 0 to 480 gallons per minute:

0 to 480 GPM
0 to 150 "WC

To DCS

HART communicator

```
Online

1 Device setup
2 PV      21.67 inH2O
3 AO      10.08 mA
4 LRV     0.000 inH2O
5 URV    150.00 inH2O
```
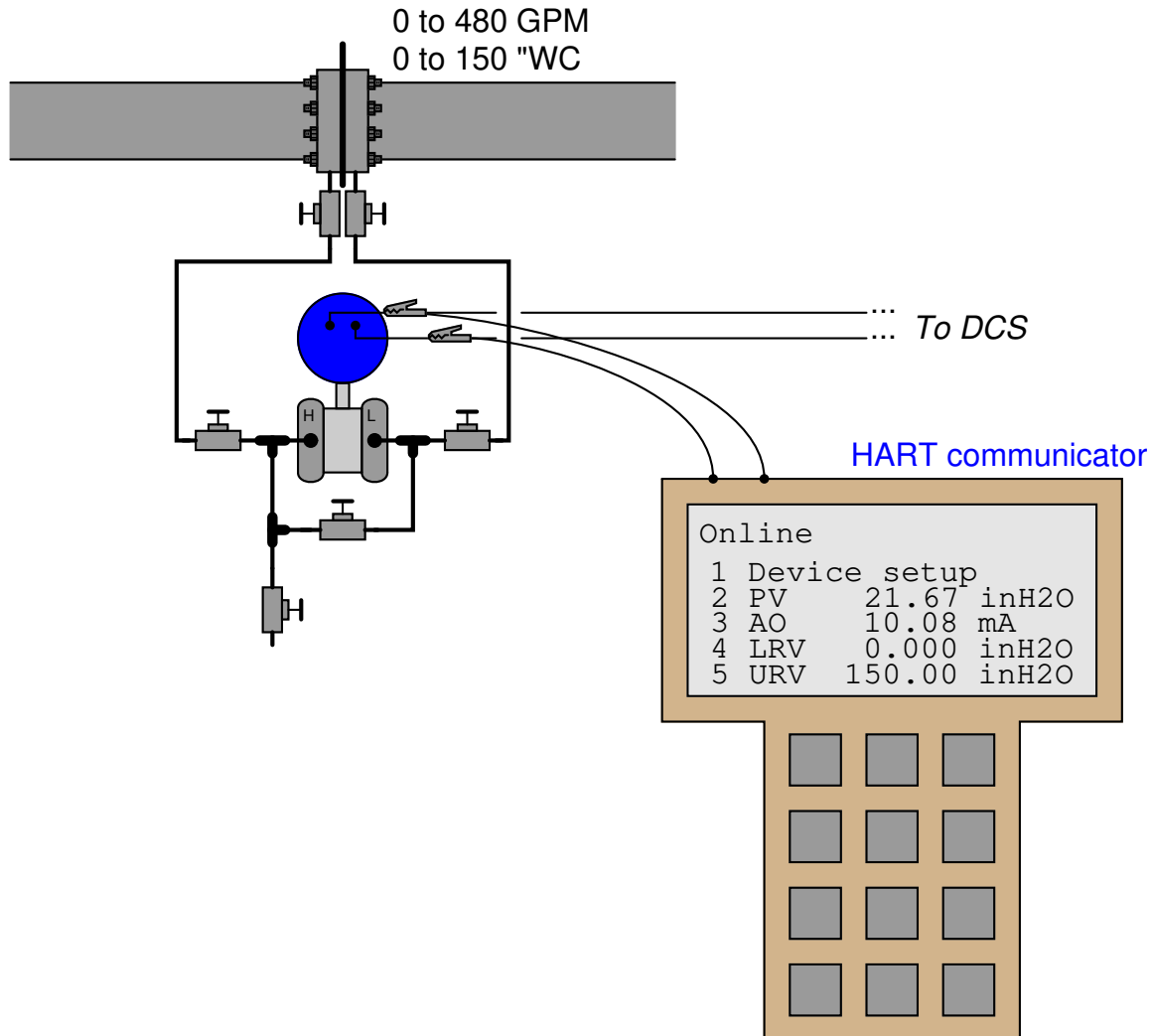
Operations personnel have strong reason to believe that the actual flow rate through this pipe is 160 GPM, yet the DCS registers a flow rate of 182.4 GPM. Based on this information, determine the likely source of calibration error in this system. Also determine whether this transmitter has square-root characterization enabled or not.

Additionally, suggest a good "next step" to perform to either pinpoint the location of this problem or correct it.

<u>file i03443</u>

Oppgave 20

A "smart" (digital) DP flow transmitter configured for square-root characterization is removed from service and taken to a calibration bench for testing. A technician connects a precision pressure gauge and air source to the transmitter's high port while monitoring the 4-20 mA output signal using a DMM:
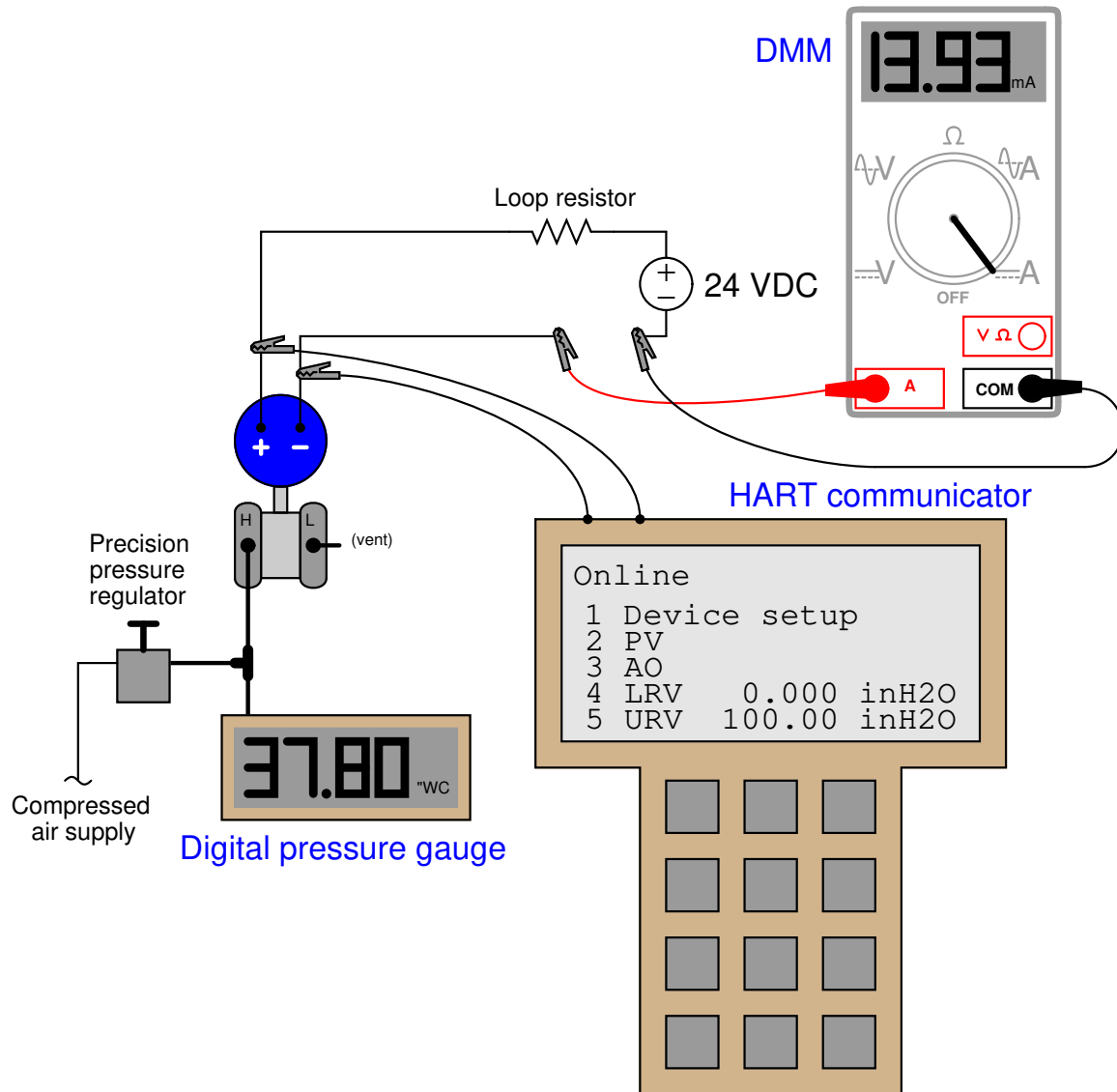
Determine what **PV** and **AO** values will be displayed on the HART communicator display if the calibration error lies entirely in the sensor (i.e. the transmitter requires a sensor trim) versus if it lies entirely in the digital-analog converter (i.e. the transmitter requires an output trim).

Parameter	If sensor trim error	If output trim error
PV		
AO		

file i03473

Pressure transmitter PT-89 on this natural gas separator vessel presently has a calibrated range of 0 to 400 PSIG. Operations personnel would like you to re-range this transmitter for 300 to 375 PSIG instead:
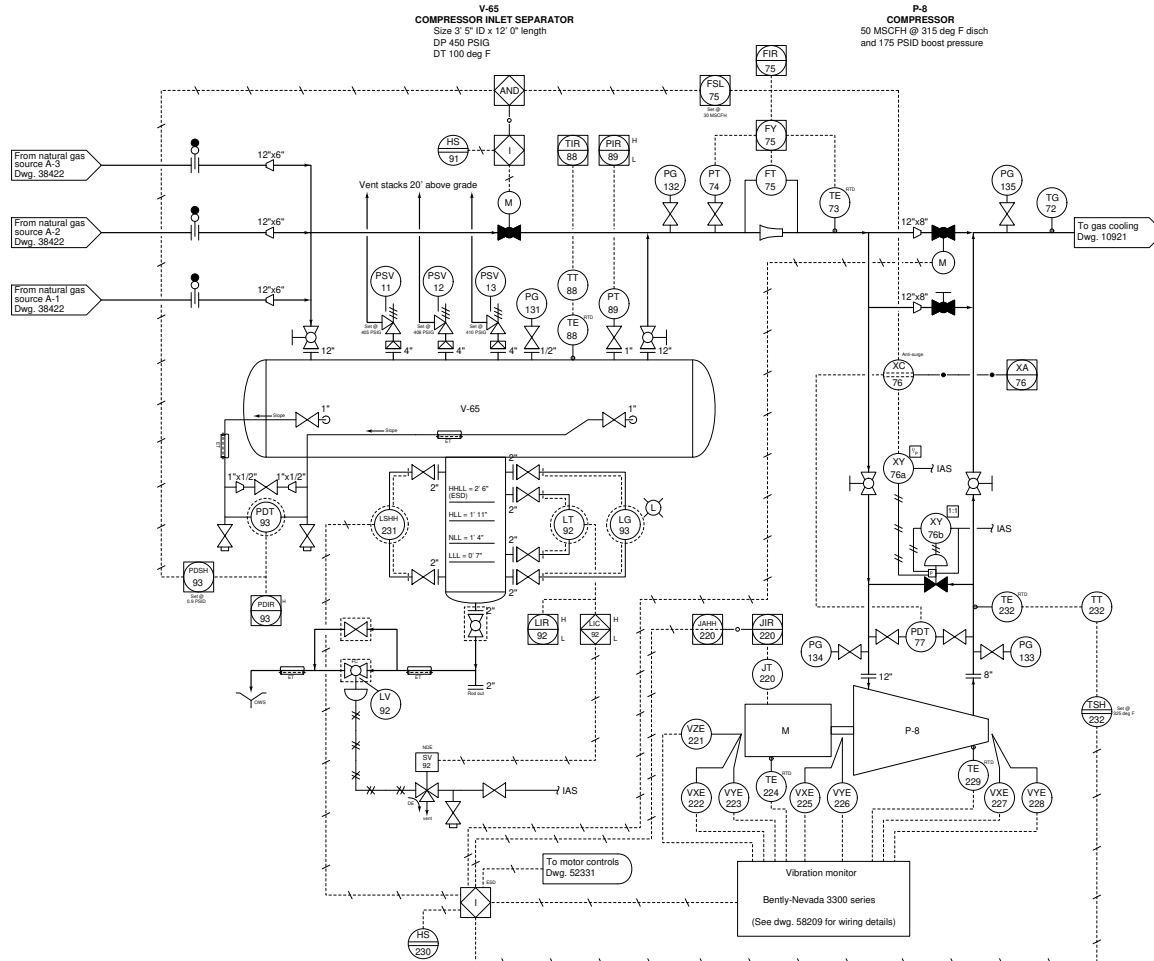
Answer the following questions about the task of re-ranging, explaining each of your answers:

- Does the new, requested range constitute a *zero* shift, a *span* shift, or both?

- If this is a "smart" (digital) transmitter, does it need to be *re-trimmed* as well as *re-ranged*?

- Will the control room indicator PIR-89 need to be *re-calibrated*, *re-ranged*, or both?

- Will the local pressure gauge PG-131 need to be *re-calibrated* as well?

- Will the pressure safety valves PSV-11, PSV-12, and/or PSV-13 need to be set for lower "lift" pressures?

- If the maximum (factory) range of this pressure transmitter is 0 to 750 PSI and the maximum turndown ratio for the required accuracy is 20:1, will it be able to meet

the new range? If not, what might you have to do in order to fulfill operations' request?

- Why do you suppose operations would like you to re-range this transmitter? In other words, what operational advantage(s) might be gained from doing so? Are there any potential disadvantages of having the new range versus the old?

Oppgave 22

Suppose you are going to install a Rosemount model 1151 "Alphaline" (analog) differential pressure transmitter in a process, calibrated to a range of 0 to 100 inches W.C. The transmitter's model number shows the following specifications:

- Model = *1151DP*

- Pressure range code = *4*

- Output code = *E*

- Material code = *22*

Answer the following questions regarding this transmitter as it applies to the application you intend to install it in:

- Does this transmitter have sufficient turndown ("rangeability") for the application? Show your calculation to prove whether it does or not.

- Calculate the expected accuracy for this transmitter once installed, expressed in $\pm$ inches of water column.

- Calculate the six-month calibration stability of this transmitter after installation, expressed in $\pm$ inches of water column.

- Calculate the amount of total measurement error this transmitter may exhibit given an ambient temperature shift of 65 degrees Fahrenheit, expressed in $\pm$ inches of water column.

Oppgave 23

An instrument technician wants to create a temperature reference for a thermocouple transmitter by freezing some water, knowing that the freezing point of water at sea level is 32° F (or 0° C). He inserts the thermocouple into a cup of water, then sets the cup and thermocouple inside a freezer until the water is frozen solid. He then takes the cup out of the freezer and connects the thermocouple to the temperature transmitter for calibration. What is wrong with the technician's procedure? What must be done differently to ensure a reference temperature of 32° F (0° C) at the thermocouple tip?

Suggestions for Socratic discussion

- Refer to a *phase diagram* to identify points where H_2O maintains a very stable temperature despite changes in surrounding pressure.

- Explain how the *triple point* of water is used in metrology laboratories to maintain both stable temperature and stable pressure for instrument calibration purposes.

file i00355

Oppgave 24

An analog-to-digital converter (ADC) has a calibrated input range of 0 to 5 volts, and a 12-bit output. Complete the following table of values for this converter, assuming perfect calibration (no error):

Input voltage (volts)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
1.6			
		3022	
	40		
			A2F

Suggestions for Socratic discussion

- Calculate the resolution of this ADC in *percent* of full-scale range. In other words, what is the smallest percentage of input signal change it is able to resolve?

file i03822

26

Oppgave 25

An analog-to-digital converter (ADC) has a calibrated input range of 0 to 10 volts, and a 12-bit output (0 to 4095 "count" range). Complete the following table of values for this converter, assuming perfect calibration (no error):

Input voltage (volts)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
	0		
	25		
	50		
	75		
	100		

file i03823

Oppgave 26

An analog-to-digital converter (ADC) has a calibrated input range of 0 to 10 volts, and a 16-bit output (0 to 65535 "count" range). Complete the following table of values for this converter, assuming perfect calibration (no error):

Input voltage (volts)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
	0		
	25		
	50		
	75		
	100		

file i03824

Oppgave 27

A digital pressure transmitter has a calibrated input range of 0 to 75 PSI, and a 14-bit output (0 to 16383 "count" range). Complete the following table of values for this transmitter, assuming perfect calibration (no error):

Input pressure (PSI)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
	0		
	36		
	62		
	89		
	95		

file i03825

Oppgave 28

A digital pressure transmitter has a calibrated input range of 50 to 200 PSI, and a 10-bit output (0 to 1023 "count" range). Complete the following table of values for this transmitter, assuming perfect calibration (no error):

Input pressure (PSI)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
	7		
	22		
	39		
	56		
	78		

Oppgave 29

A digital level transmitter has a calibrated input range of 20 to 170 inches of liquid level, and a 10-bit output (0 to 1023 "count" range). Complete the following table of values for this transmitter, assuming perfect calibration (no error):

Input level (inches)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
	11		
	28		
	55		
	73		
	92		

file i03827

Oppgave 30

A computer spreadsheet program may be used as a simulator for an analog-digital converter, taking an analog voltage signal value and converting it into a digital "count" value. Begin creating your own spreadsheet by following the format shown below, allowing anyone to enter an analog input value in volts, while the spreadsheet calculates the "count" value and displays it in decimal, binary, and hexadecimal formats. Note that the yellow and blue shading in this example spreadsheet is strictly for aesthetic value (distinguishing input values from calculated values) and is not necessary for the spreadsheet to function:

	1	2	3	4	5
1	Input (V)		Counts (decimal) =	179	
2	3.5		Counts (binary) =	10110011	
3			Counts (hex) =	B3	
4					
5					

Assume a 0 to 5 volt analog input range, and a 8-bit (00 to FF hex) digital output range.

Suggestions for Socratic discussion

- How could you modify the spreadsheet to have its analog input range be user-adjustable? In other words, allowing anyone to simulate the performance of a 0 to 10 volt range or 0 to 20 volt range without having to modify any of the formulae in the spreadsheet?

- How could you *test* your spreadsheet cable-length calculator for accuracy (to verify you haven't made any mistakes) once you've entered all your equations?

file i04408

Oppgave 31

Complete the calibration table for this flow-measuring loop, consisting of an orifice plate, ΔP transmitter, square root extractor, and indicator. Assume the following instrument ranges:
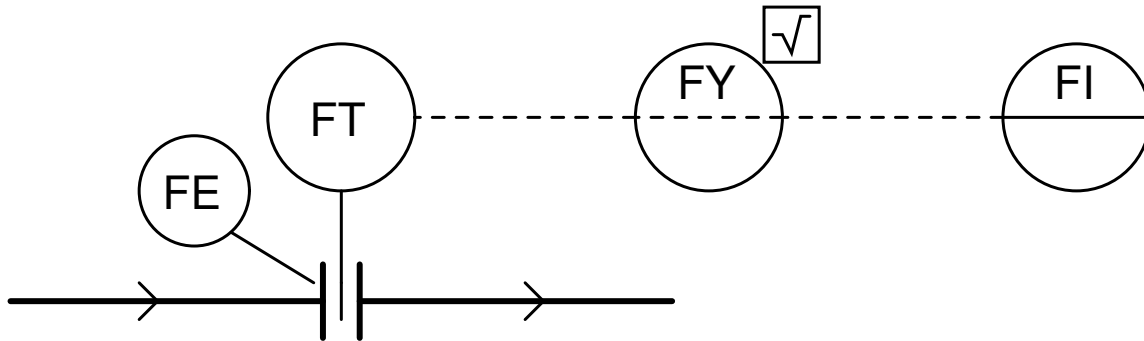
- FE: 0-750 GPM, 0-100 "W.C. ΔP

- FT: 0-100 "W.C. in, 4-20 mA out (linear)

- FY: 4-20 mA in and out (square-root)

- FI: 4-20 mA in, 0-750 GPM indication

Flow rate (GPM)	Percent of max. flow (%)	Orifice ΔP ("W.C.)	FT output signal (mA)	FY output signal (mA)	FI indication (GPM)
0	0				0
	10				
	25				
375	50				375
	75				
	90				
750	100				750

Oppgave 32

Complete the calibration table for this flow-measuring loop, consisting of an orifice plate, ΔP transmitter, square root extractor, and indicator. Assume the following instrument ranges:
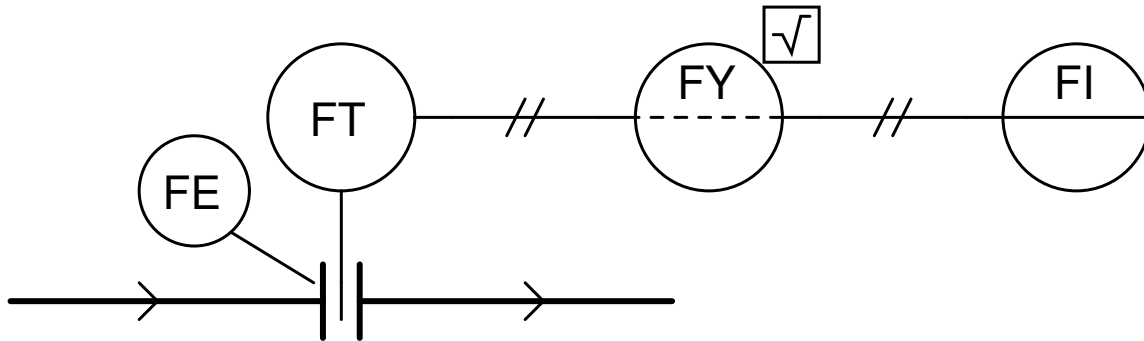
- FE: 0-400 GPM, 0-125 "W.C. ΔP

- FT: 0-125 "W.C. in, 3-15 PSI out (linear)

- FY: 3-15 PSI in and out (square-root)

- FI: 3-15 PSI in, 0-400 GPM indication

Flow rate (GPM)	Percent of max. flow (%)	Orifice ΔP ("W.C.)	FT output signal (PSI)	FY output signal (PSI)	FI indication (GPM)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

file i00693

Oppgave 33

Suppose you are calibrating a panel-mounted indicator to be used for displaying flow rates, based on the signal coming from a (linear) DP transmitter sensing pressure across a venturi tube. The DP transmitter is an analog electronic transmitter with a linear characteristic, which means the panel-mounted indicator must be configured for square-root characterization.

Calculate the ideal display value at the following input currents, assuming a calibrated range of 0 to 700 GPM for the indicator:

Input current (mA)	Displayed flow (GPM)
4	
6	
9.3	
13	
14.8	
20	

- Suppose this analog transmitter were connected to an analog meter to indicate flow. How could the necessary square-root characterization be performed when all the components are analog and not digital?

file i04052

Oppgave 34

An electric-to-pneumatic signal transducer has an input range of 4-20 mA and an output range of 3-15 PSI. Complete the following table of values, assuming zero calibration error. Show the equations used to calculate all values given the percentage of span (x):

| Input current (mA)	Percent of span (%)	Output pressure (PSI)
6.6		
		8.5
	71	
		4.7

Equations used:

Input current =

Output pressure =

file i00057

Oppgave 35

In instrumentation parlance, a *transducer* is a calibrated device used to convert one standardized signal into another standardized signal. One very common form of transducer is an *I/P transducer*, which converts an electric current signal into a pneumatic pressure signal:
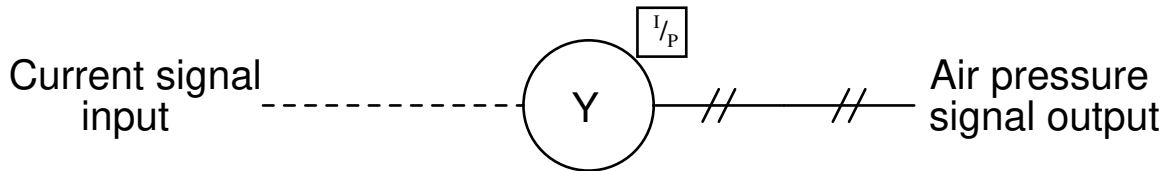
The symbols shown above are standard for process and instrumentation diagrams (P&ID's), where an electric cable is shown as a dashed line, a pneumatic pipe or tube shown as a line with double hash-marks periodically drawn through it, and the instrument is a circle with letters (in this case, "Y", representing a signal relay, computing element, transducer, or converter).

The most popular range for electric current signals is 4 to 20 mA DC. The most common range for pneumatic (air pressure) signals is 3 to 15 PSI. Therefore, the most common type of I/P transducer has an input range of 4-20 mA and an output range of 3-15 PSI. Both of these ranges are there to represent some measured or manipulated quantity in an instrument system. That is, 0% of range will be represented by a 4 mA input signal to the I/P, and a 3 PSI output signal; 100% of range will be represented by a 20 mA input signal and a 15 PSI output signal; 50% range will be represented by a 12 mA input and a 9 PSI output.

Complete all the missing data in the following calibration table for this I/P transducer, and then describe how you were able to correlate the different percentages of range with specific current and pressure signal values:

Input current (mA)	Percent of range (%)	Output pressure (PSI)
4	0	3
	10	
	20	
	25	
	30	
	40	
12	50	9
	60	
	70	
	75	
	80	
	90	
20	100	15

Challenge: build a computer spreadsheet that calculates all current and pressure values from given percentages.

file i00084

Oppgave 36

Suppose you had a current-to-pressure ("I/P") transducer with an output range of 3 to 15 PSI and an input range of 4 to 20 mA. The following calibration table shows several input signal levels and their corresponding percentages of span and output pressures:

Input signal applied (mA)	Percent of span (%)	Output pressure (PSI)
6.88	18	5.16
5.1	6.88	3.83
12.8	55	9.6
17.44	84	13.08
6.53	15.83	4.9

While the calculations for obtaining percent and output pressure (PSI) from input current (mA) values are not very complex, they can be tedious. A powerful computer-based tool for relieving this tedium is a type of application called a *spreadsheet*. A very common example of spreadsheet software is Microsoft *Excel* (although other spreadsheet programs exist, some of them free!).

A spreadsheet program presents a screen full of rectangular *cells* into which text, numerical values, and mathematical formulae may be entered. Each cell is "addressed" by a system of row and column designators, traditionally numbers for rows and letters for columns (like the classic game of "Battleship" where coordinates on a grid-map are called out by letter and number combination) but a more modern convention designates both rows and columns by number.

We may set up a spreadsheet to calculate percentage values for this I/P based on input currents as follows. The yellow and blue cell shading (color fill) shown in this example is entirely optional, but helps to distinguish number-entry fields from calculated-value fields (the number in the yellow cell R2C1 is the milliamp value you type in to the spreadsheet, while the number in the blue cell R2C3 is the PSI value calculated by the spreadsheet):

	1	2	3	4	5
1	Input (mA)		Percent		
2	6.88		18.0		
3					
4					
5					

What follows is a list of cell entries needed to create the spreadsheet display you see above:

- **Cell R1C1:** Input (mA)

- **Cell R2C1:** 6.88

- **Cell R1C3:** Percent

- **Cell R2C3:** = (R2C1 - 4) / 16   *(select "%" display formatting)*

The text inside cells R1C1 and R1C3 is not essential for the spreadsheet to function – like the color shading, they merely serve as labels to help describe what the number values mean. The formula entered into cell R2C3 begins with an equals sign (=), which tells the spreadsheet to regard it as a formula rather than as text to be displayed verbatim as in R1C1 and R1C3. Note how the formula references the numerical value located in the "row 2 column 1" cell by calling it "R2C1". This allows the user to enter different values into cell R2C1, and the spreadsheet will automatically re-calculate the percentage for each entered mA value. Thus, if you were to edit the contents of cell R2C1 to hold 12.8 instead of 6.88, the value shown in cell R2C3 would update to display 55.0 instead of 18.0 as it does now.

Your first task here is to start up a spreadsheet program and enter what is shown above, then validate the accuracy of your work by entering several different current (milliamp) values and checking that the percentages for each are calculated correctly by the spreadsheet.

Now that you have successfully created this spreadsheet, add the appropriate enteries into cells R1C5 and R2C5 so that it also calculates the appropriate output pressure for the I/P, for any arbitrary input current entered into cell R2C1. When complete, your modified spreadsheet should look something like this:

	1	2	3	4	5
1	Input (mA)		Percent		Output (PSI)
2	6.88		18.0		5.16
3					
4					
5					

Show what entries you had to place into cells R1C5 and R2C5 to make this spreadsheet work.

| Suggestions for Socratic discussion |

- Identify the text character used to represent *division* in the formula shown in cell R2C3. What is the appropriate character to represent *multiplication*?

- Explain why parentheses are used in the formula in cell R2C3. *Hint: a good problem-solving approach for answering this question is to analyze what would happen if the parentheses were not there!*

- Explain what would happen if cell R2C3 were not configured to display in *percent.*

- There is more than one correct formula to enter into cell R2C5 to properly calculate the output pressure in PSI. One formula references the percentage value (located at R2C3), while the other formula references the milliamp value (located at R2C1). Compare these two formulae, and explain which one makes more sense to you.

- Explain how a spreadsheet is such a powerful mathematical tool for performing "tedious" calculations such as instrument input/output responses. Can you think of any other practical uses for a spreadsheet?

file i01626

Oppgave 37

An electronic differential pressure transmitter with remote (chemical) seals is used to measure the level of liquid in this pressurized vessel. The specific gravity of fill fluid in both remote seals is 0.934. The range of liquid level measurement is 0 to 24 feet, and the output signal range is 4 to 20 mA. Assume a calibration tolerance of $+/-$ 0.25 percent. Complete the following table of values for this transmitter. Show the equations used to calculate all values given the percentage of span (x):

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Equations used:

Process level =

Pressure sensed =

Output signal (ideal) =

Output signal (min.) =

Output signal (max.) =

<u>file i00033</u>

Oppgave 38

An ultrasonic level transmitter has a calibrated range of 40 to 75 inches and its output signal range is 4 to 20 mA. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured level (inches)	Percent of span (%)	Output signal (mA)
47		
		6
	75	
60		
		15.1
	34	

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00098

A liquid storage vessel holding a very corrosive liquid has its level measured by a *bubbler* system, whereby a transmitter measures the backpressure of air inside a "dip tube" inserted into the vessel:
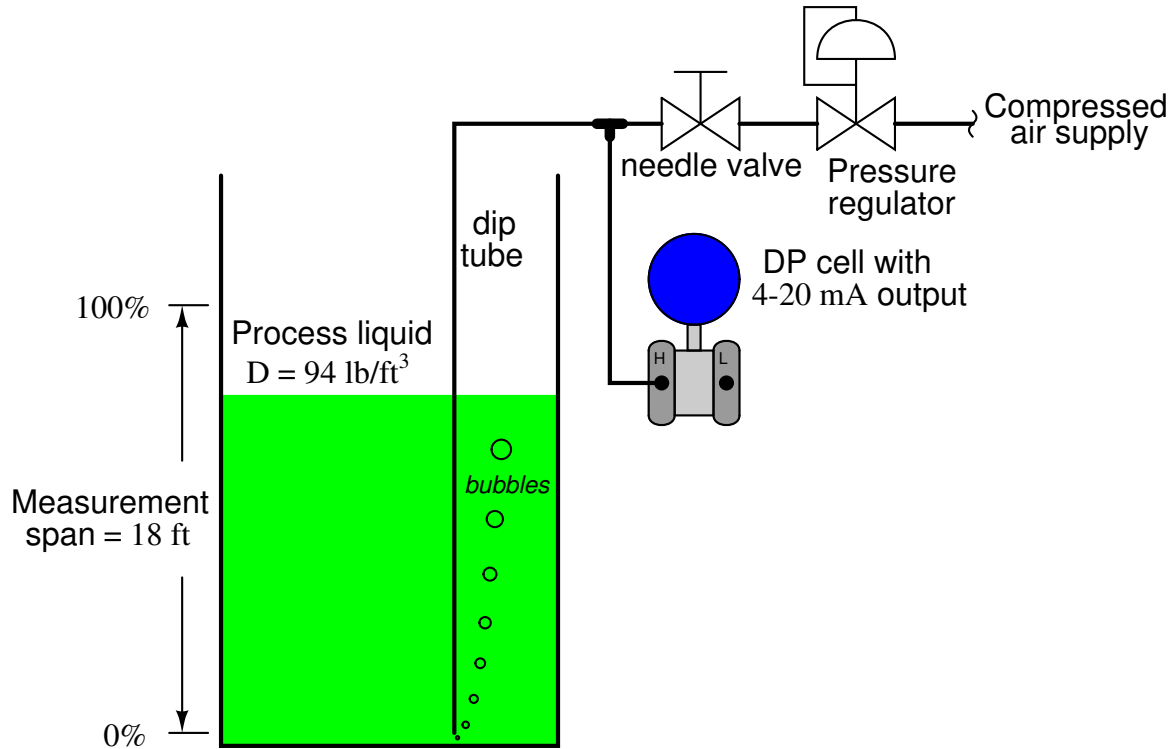
Explain how this level measurement system works, and how it protects the DP cell from the corrosive effects of the process liquid.

Also, complete a calibration table for the differential pressure transmitter in this level measurement scenario, with a calibration tolerance of $\pm$ 0.5%. Assume that the lower range-value of the process (0% level) is exactly the same height as the bottom of the dip tube:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Suggestions for Socratic discussion

- The dip tube (or "bubbler") system does indeed isolate the transmitter from the corrosive process liquid, but how can the dip tube itself survive? And, if the dip

tube is able to survive in the corrosive liquid (just like the vessel), why can't we find a DP cell that can handle it directly without the isolation of a dip tube system?

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

- What is your recommendation for setting the position of the needle valve in this bubble tube system? Exactly how far open is "open enough," and more importantly for what reason?

- What would happen if the end of the dip tube were to become plugged with debris, blocking all flow?

- What would happen if the needle valve were to become plugged with debris, blocking all flow?

- What would happen if the pressure regulator were to become plugged with debris, blocking all flow?

- Add one or more hand valves to the tubing in this system to provide operators with a simple means of unblocking a plugged dip tube using high-pressure compressed air.

- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the bottom of the vessel.

- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the bottom of the dip tube.

- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the transmitter's "H" port.

- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the downstream side of the needle valve.

- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the upstream side of the needle valve.

file i00249

Oppgave 40

The following storage vessel holds water. The hydrostatic-pressure level transmitter is located 5 meters below the bottom of the vessel, and the desired level measurement range is 8 meters to 12 meters:
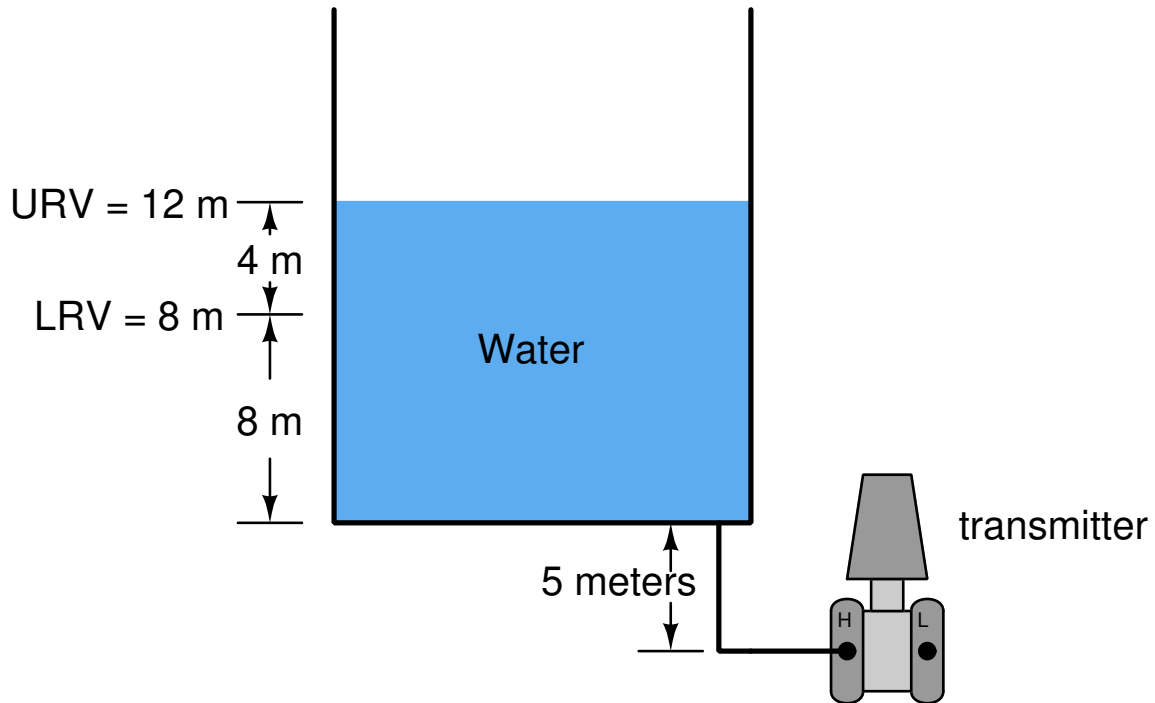
Assuming a pneumatic transmitter with an output range of 4 mA to 20 mA, and a calibration accuracy of +/- 1% of span, complete the following calibration table for the transmitter:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

file i00257

Oppgave 41

The following storage vessel holds a liquid with a density of 60 lb/ft³. The ΔP transmitter is located 5 feet above the bottom of the vessel and has a remote seal with capillary tubing whose fill fluid has a specific gravity of 1.9. The desired level measurement range is 0 feet to 11 feet:
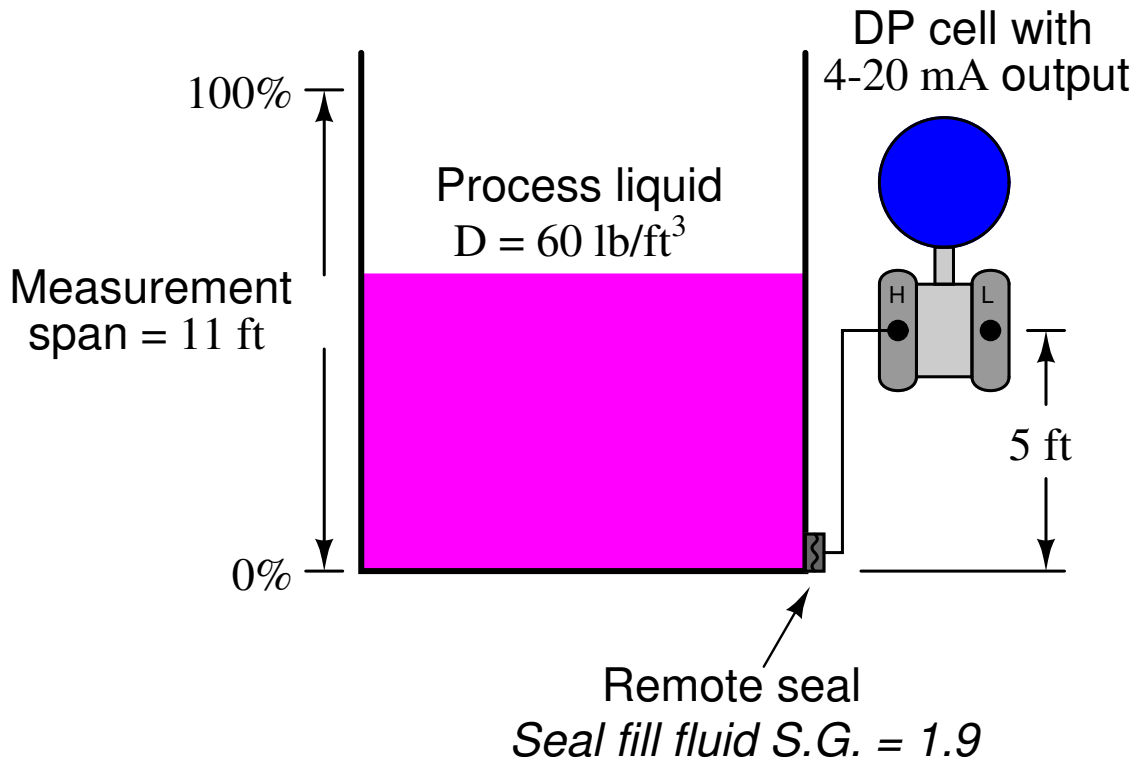

Assuming an electronic transmitter with an output range of 4 to 20 mA, and a calibration accuracy of $\pm$ 0.2% of span, complete the following calibration table for the transmitter:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Be sure to show all your mathematical work so that your instructor will be able to check the conceptual validity of your technique(s). A good way to check to see if you're solving the problem correctly is to check that each and every one of your intermediate calculations (i.e. the results you get mid-way during the process to arrive at the final answer) has real physical meaning. **If you truly understand what you are doing, you will be able to identify the correct unit of measurement for every intermediate result and also be able to show where that number applies to the scenario at hand**.

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

- Suppose this vessel were enclosed at the top, and a remote-sealed compensating leg connected from the transmitter's "L" port to the top of the vessel. How would this change the transmitter's necessary calibration? Would it require an adjustment in zero, span, linearity, or some combination of these?

- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the bottom of the vessel.

- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the capillary tube (at the remote seal).

- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the capillary tube (at the transmitter "H" port).

file i00261

Oppgave 42

Determine a basic 5-point (0%, 25%, 50%, 75%, and 100%) calibration table for the level transmitter in this scenario. Assume a calibration tolerance of +/- 0.5%:

Process level (in)	Percent of span (%)	Differential pressure ("W.C.)	Output signal ideal (PSI)	Output signal min. (PSI)	Output signal max. (PSI)
	0				
	25				
	50				
	75				
	100				

file i00322

Oppgave 43

Calculate values for the following calibration table, for a transmitter measuring liquid level interface (densities = 50 lb/ft^3 and 70 lb/ft^3), with a calibration tolerance of $\pm$ 1% and a 4-20 mA output range:

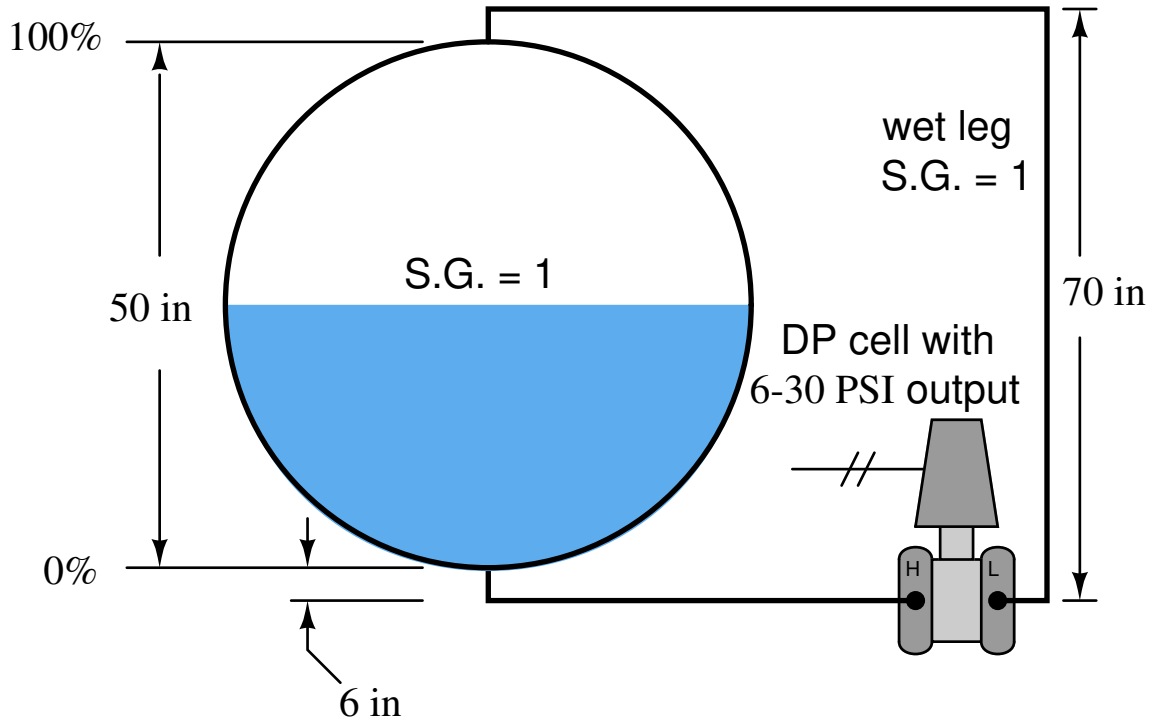| Interface level (in)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Suggestions for Socratic discussion

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00686

Oppgave 44

A Foxboro pneumatic square root extractor has a calibrated range of 3 to 15 PSI for both input and output. Complete the following table of values for this relay, assuming perfect calibration (no error). Be sure to show your work!

Input signal (PSI)	Percent of input span (%)	Percent of output span (%)	Output signal (PSI)
5			
13			
	50		
	30		
		80	
		15	
			7
			12

| Suggestions for Socratic discussion |

- Why are pneumatic square-root extractors all but obsolete in modern industry? What has replaced their functionality?

- Share problem-solving techniques for obtaining answers to this problem.

file i00100

Oppgave 45

An electronic pressure transmitter has a calibrated range of 100 to 300 PSI, and its output signal range is 4 to 20 mA. Complete the following calibration table for a calibration tolerance of +/- 0.5% (of span), and be sure to show the equations used to calculate all the parameters given the percentage of span (x):

Input pressure applied (PSI)	Percent of span (%)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0			
	10			
	25			
	50			
	75			
	90			
	100			

Equations used:

Input pressure =

Output signal (ideal) =

Output signal (min.) =

Output signal (max.) =

Oppgave 46

A pneumatic pressure transmitter has a calibrated range of 50 to 250 PSI, and its output signal range is 3 to 15 PSI. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Input pressure applied (PSI)	Percent of span (%)	Output signal (PSI)
	30	
58		
		7.5
		13.7

Oppgave 47

An electronic pressure transmitter has a calibrated range of -10 to 60 PSI, and its output signal range is 4 to 20 mA. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Input pressure applied (PSI)	Percent of span (%)	Output signal (mA)
0		
-5		
		12
		13.6
	40	
	22	

file i00095

Oppgave 48

A pneumatic differential pressure transmitter has a calibrated range of -100 to $+100$ inches of water column (" W.C.), and its output signal range is 3 to 15 PSI. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Input pressure applied ("W.C.)	Percent of span (%)	Output signal (PSI)
0		
-30		
		8
		13
	65	
	10	

Suggestions for Socratic discussion

- Develop a linear equation in the form of $y = mx + b$ that directly relates input pressure (x) to output pressure (y).

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00096

Oppgave 49

Suppose you wish to calibrate a pneumatic pressure transmitter to an input range of 0 to 200 inches of water, with an output range of 3 to 15 PSI. Complete the following calibration table showing the test pressures to use and the allowable low/high output signals for a calibrated tolerance of +/- 0.5% (of span):

Input pressure applied (" W.C.)	Percent of span (%)	Output signal *ideal* (PSI)	Output signal *low* (PSI)	Output signal *high* (PSI)
	0			
	25			
	50			
	75			
	100			

Suppose this transmitter is installed as part of a complete pressure measurement system (transmitter plus remote indicator and associated components), and the entire measurement system has been calibrated within the specified tolerance (± 0.5%) from beginning to end. If the operator happens to read a process pressure of 153 inches W.C. at the indicator, how far off might the actual process pressure be from this indicated value?

Suggestions for Socratic discussion

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00227

Oppgave 50

Suppose you wish to calibrate an electronic pressure transmitter to an input range of -50 to 300 inches of water, with an output range of 4 to 20 mA. Complete the following calibration table showing the test pressures to use and the allowable low/high output signals for a calibrated tolerance of +/- 0.1% (of span). Assume you can only use positive test pressures (no vacuum), and be sure to designate which side the test pressure should be applied to (H = high ; L = low):

Input pressure applied (" W.C.)	Percent of span (%)	Output signal *ideal* (mA)	Output signal *low* (mA)	Output signal *high* (mA)
	0			
	25			
	50			
	75			
	100			

Suppose this transmitter is installed as part of a complete pressure measurement system (transmitter plus remote indicator and associated components), and the entire measurement system has been calibrated within the specified tolerance ($\pm$ 0.1%) from beginning to end. If the operator happens to read a process pressure of 210 inches W.C. at the indicator, how far off might the actual process pressure be from this indicated value?

Suggestions for Socratic discussion

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00228

Oppgave 51

Suppose you are calibrating a DP transmitter to go into service as a flow transmitter, measuring differential pressure generated by a segmental wedge flow element. This is a "smart" electronic transmitter with square-root characterization capability, which you decide to activate for this application.

Calculate the ideal current signal values at the following calibration pressures, assuming a calibrated range of 0 to 150 inches water column:

Input pressure (" W.C.)	Output current (mA)
0	
45	
75	
90	
110	
150	

Furthermore, suppose you performed an "As-Found" test on this DP transmitter and found it to respond as such:

Input pressure (" W.C.)	Output current (mA)
0	4.3
45	13.06
75	15.61
90	16.69
110	18.0
150	20.3

What type of calibration error is this (e.g. *zero* shift, *span* shift, or *nonlinearity*), and do you suspect it lies with the sensor or with the digital-to-analog converter? In other words, do you need to perform a *sensor trim* or an *output trim* on this instrument?

Suggestions for Socratic discussion

- Explain the difference between a *sensor trim* and an *output trim* in a "smart" transmitter.

- What tool(s) would you need to perform a sensor trim on a smart transmitter?

- What tool(s) would you need to perform an output trim on a smart transmitter?

file i04051

Oppgave 52

A tachogenerator is used to measure the rotary speed of a machine. Its calibrated range is 0 to 1500 RPM (revolutions per minute) and its corresponding signal output is 0 to 10 volts DC. Given these range values, calculate the output voltages for the following input shaft speeds, and then describe how you were able to correlate the different speeds to output voltage values:

Shaft speed (RPM)	Output voltage (volts DC)
100	
350	
500	
750	
890	
975	
1230	
1410	
1500	

file i00085

Oppgave 53

A temperature transmitter has a calibrated range of -80 to 150 degrees F and its output signal range is 4 to 20 mA. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured temp (^{o}F)	Percent of span (%)	Output signal (mA)
120		
-45		
	42	
	25	
		7.5
		12.9

file i00099

Oppgave 54

A turbine flowmeter measuring cooling water for a large power generator uses an electronic circuit to convert its pickup coil pulses into a 4-20 mA analog current signal. The "K factor" for the turbine element is 0.0101 liter per pulse, and the 4-20 mA analog output is ranged from 0 to 500 l/m flow. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured flow (l/m)	Pickup signal frequency (Hz)	Percent of output span (%)	Output signal (mA)
250			
412			
	305		
	780		
		63	
		49	
			10
			16

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

- Suppose you were asked to check the accuracy of the frequency-to-current converter circuit for this flowmeter. What sort of test equipment would you use, and how could you perform the test with the flowmeter still installed in the cooling water pipe?

- Could the pulse output of the pickup coil be used directly as a flow signal, or is the converter circuit absolutely necessary?

- Explain how a PLC could be used to *totalize* the water flow through this flowmeter, to provide total usage values at the end of each day.

file i00101

Suppose you wish to calibrate a turbine flowmeter to an input range of 0 to 600 gallons per minute. The k factor for this turbine is 20 pulses per gallon, making the input frequency range 0 to 200 Hz for this flow range. The output signal range is 4 to 20 mA. Complete the following calibration table showing the proper test frequencies and the ideal output signals at those levels:

Simulated flow rate (GPM)	Input frequency applied (Hz)	Percent of span (%)	Output signal (mA)
97			
		25	
		60	
400			

file i02996

Oppgave 56

An important part of performing instrument calibration is determining the extent of an instrument's error. Error is usually measured in *percent of span*. Calculate the percent of span error for each of the following examples, and be sure to note the sign of the error (positive or negative):

- **Pressure gauge**
- LRV = 0 PSI
- URV = 100 PSI
- Test pressure = 65 PSI
- Instrument indication = 67 PSI
- Error = _____ % of span

- **Weigh scale**
- LRV = 0 pounds
- URV = 40,000 pounds
- Test weight = 10,000 pounds
- Instrument indication = 9,995 pounds
- Error = _____ % of span

- **Thermometer**
- LRV = -40°F
- URV = 250°F
- Test temperature = 70°F
- Instrument indication = 68°F
- Error = _____ % of span

- **pH analyzer**
- LRV = 4 pH
- URV = 10 pH
- Test buffer solution = 7.04 pH
- Instrument indication = 7.13 pH
- Error = _____ % of span

Also, show the math you used to calculate each of the error percentages.

Challenge: build a computer spreadsheet that calculates error in percent of span, given the LRV, URV, test value, and actual indicated value for each instrument.
file i00089

Oppgave 57

An error tolerance of $\pm$ 0.4% of span is _____ milliamps for a 4-20 mA instrument signal.

Oppgave 58

Suppose you are going to install a Rosemount model 1151 "Alphaline" (analog) differential pressure transmitter in a process, calibrated to a range of 0 to 100 inches W.C. The transmitter's model number shows the following specifications:

- Model = *1151DP*

- Pressure range code = *4*

- Output code = *E*

- Material code = *22*

Answer the following questions regarding this transmitter as it applies to the application you intend to install it in:

- Does this transmitter have sufficient turndown ("rangeability") for the application? Show your calculation to prove whether it does or not.

- Calculate the expected accuracy for this transmitter once installed, expressed in $\pm$ inches of water column.

- Calculate the six-month calibration stability of this transmitter after installation, expressed in $\pm$ inches of water column.

- Calculate the amount of total measurement error this transmitter may exhibit given an ambient temperature shift of 65 degrees Fahrenheit, expressed in $\pm$ inches of water column.

Oppgave 59

A pressure calibration device called a *deadweight tester* generates very precise pressures by means of calibrated weights placed on top of a hydraulic piston:

Deadweight tester
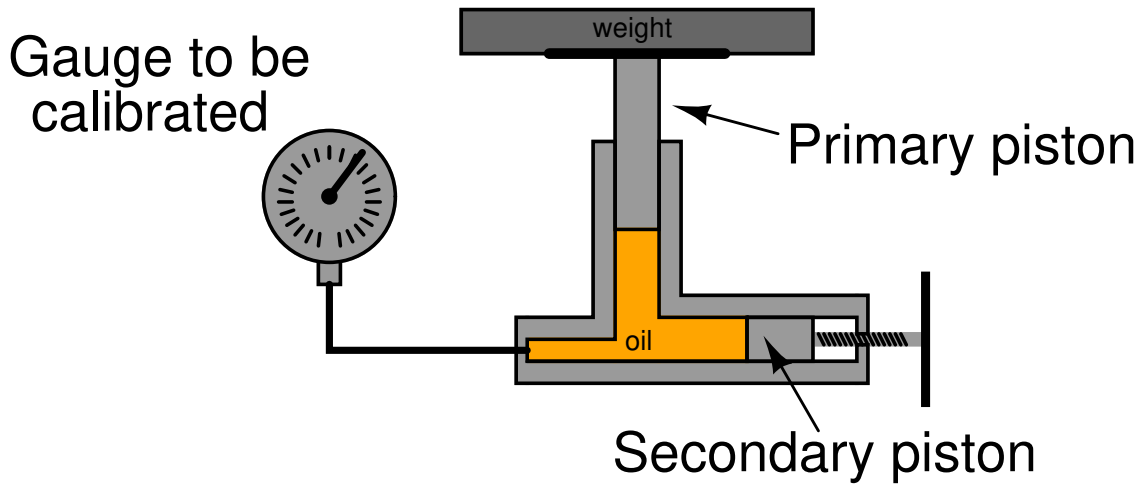
The secondary piston is moved in and out by turning a handle on a threaded rod. Its sole purpose is to displace enough oil to force the primary piston to rise from its resting position, so that it is entirely suspended by oil pressure. In that condition, the gauge will be subject to whatever pressure is proportional to the weights placed on top of the primary piston, and the area of the primary piston.

What will happen to the gauge's indication if the secondary piston is pushed in further? What will happen to the gauge's indication if the secondary piston is pulled out, but not so far that the primary piston comes down to its resting position? In other words, what effect does the secondary piston *position* have on pressure applied to the gauge?
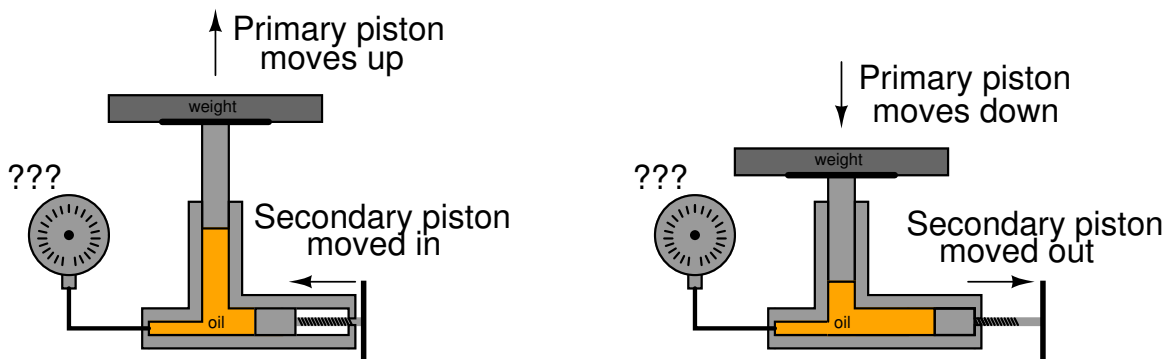
In each condition, what happens to the gauge's indication?
Does the applied pressure increase, decrease, or stay the same?

Suggestions for Socratic discussion

- Why are deadweight testers considered accurate *standards* for fluid pressure? What is it about their design and operation that makes them so accurate? Conversely, what aspects of their construction would have to change in order to corrupt their inherent accuracy?

- If a technician changes the type of fluid used in a deadweight tester (for example, from one type of oil to another), will its accuracy change?

- Identify some potential problems one might encounter when using a deadweight tester. What things, specifically, do you see that could go wrong with this device?

file i00153

Oppgave 60

Answer the following four questions about deadweight testers:

(1) What is it about the nature of a deadweight tester that makes it so accurate and repeatable? To phrase this question in the negative, what would have to change in order to affect the accuracy of a deadweight tester's output pressure?

(2) Why is it important for a deadweight tester to be *level* while it is being used to calibrate a pressure instrument?

(3) What effect will trapped air have inside a deadweight tester?

(4) Why is it advisable to *gently* spin the primary piston and weights while the piston is suspended by oil pressure?

file i00154

Oppgave 61

Two flow-indicating instruments employ a common orifice plate to measure the flow of water through a pipe. The full differential pressure generated by this orifice plate at its rated flow of 800 GPM is 120 inches water column (120 "WC):

- Receiver gauge (3-15 PSI input) connected to the output of a pneumatic DP transmitter connected across the orifice, registering 385 GPM on a 0-800 GPM square-root scale

- Panel-mounted indicator (3-15 PSI) connected to the output of the same pneumatic DP transmitter, registering 403 GPM on a 0-800 GPM square-root scale

Based on this information, where do you think the calibration error is located? If there isn't enough information yet to pinpoint the location of the error, devise a test to reveal where the error is.
file i00733

Svar

Svar 1

This is a graded question – no answers or hints given!

Svar 2

15.43 milliamps of current equates to a percentage value of 71.44%:

$$\frac{15.43 - 4}{16} \times 100\% = 71.44\%$$

This, in turn, represents a pH value of:

$$0.7144 \times (12 - 2) + 2 = 9.144 \text{ pH}$$

This largely agrees with the controller's display, which tells us there is a *slight* calibration error on either the part of the controller or the resistor. The huge discrepancy between this calculated pH value and what the hand-held pH meter registers, however, tells us there is either a problem with the pH transmitter, the pH probe, or the hand-held meter. We may further conclude there is no problem with the 250 Ω resistor or the indicating controller.

The proper setup of the loop calibrator is to place it into the "READ" (measure) mode so that it functions as a simple ammeter, then connect it in series with the output of the 4-wire transmitter. This may be done either with the indicating controller still in the circuit, or removed from the circuit.

Svar 3

This is a graded question – no answers or hints given!

Svar 4

The error lies either with the DP transmitter (FT-20), unequal fluid inside the impulse tubes, or with the orifice plate itself (FE-20). One quick check would be to drain the impulse tubes (allowing fresh process gasoline to fill the tubes) and seeing whether that fixes the problem. It's a quick procedure and it would eliminate that problem from the realm of possibility.

Another way to diagnose the problem is to remove FT-20 from service and test its calibration with applied pressures to its "H" side port. If FT-20 checks out okay, the problem must be with the impulse tubes or the orifice plate.

Svar 5

The error lies with the indicator (FI-20).

Svar 6

This is a graded question – no answers or hints given!

Svar 7

This is a graded question – no answers or hints given!

Svar 8

Svar 9

The transmitter is at fault, not the indicator.

This is a graded question – no answers or hints given!

This is a graded question – no answers or hints given!
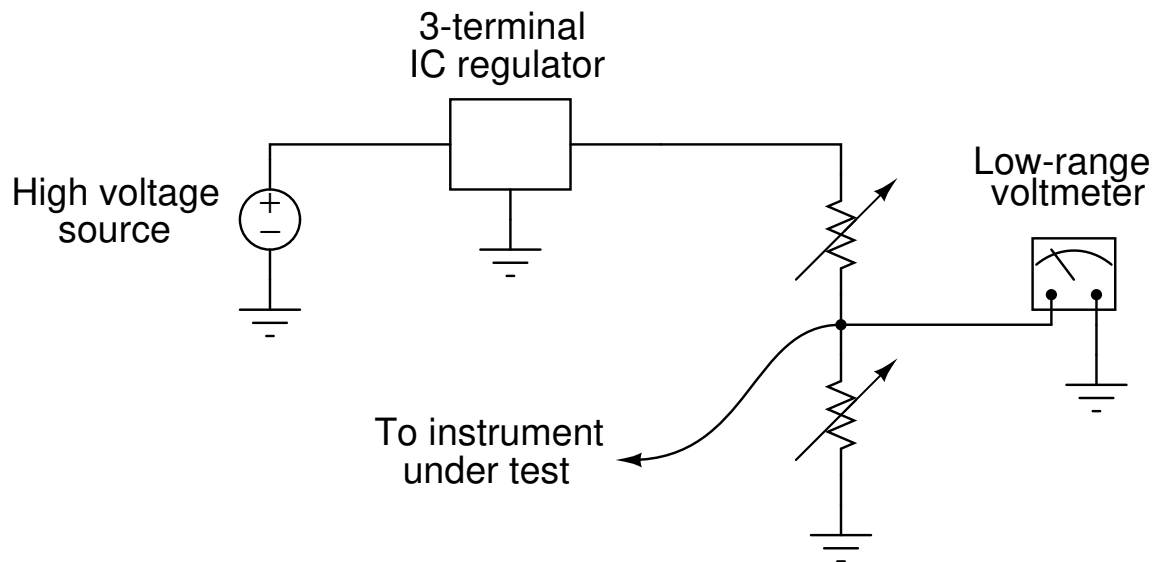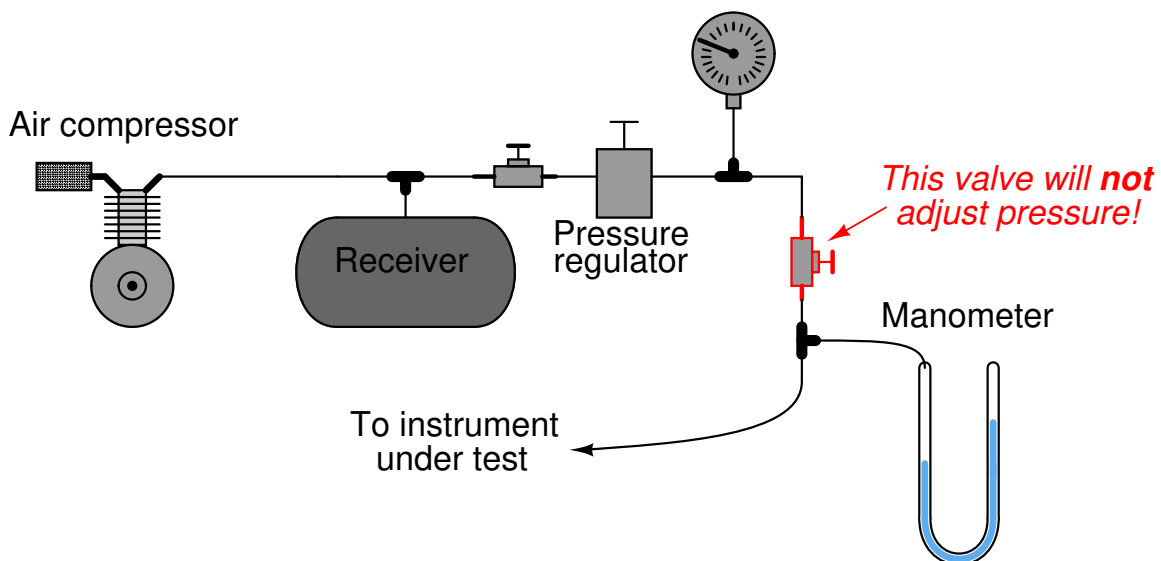
I'll leave the explanation to you!

Follow-up question #1: explain what you could do with one or both of the two needle valves to *increase* the amount of pressure sent to the instrument under test.

Follow-up question #2: explain why placing a valve in "series" with the regulator's output will *not* adjust pressure to the instrument under test or the manometer.

Svar 13

Hysteresis and dead band are not exactly the same type of calibration error, but they are closely related. "Dead band" refers to a range of instrument measurement during reversal of input where the output does not change at all. A common example of this is a "loose" steering system in an automobile, where the steering wheel must be turned excessively to take up "backlash" (mechanical slack) in the linkage system.

Hysteresis refers to the situation where a reversal of input causes an immediate, but not proportionate, reversal of output. This is commonly seen in air-actuated valves, where air pressure acts against the action of a large spring to precisely position a valve mechanism. Ideally, the valve mechanism will move proportionally to the air pressure signal sent to it, and this positioning will be both repeatable and accurate. Unfortunately, friction in the valve mechanism produces hysteresis: a different air pressure signal may be required to position the valve mechanism at the same location opening versus closing, but unlike dead band, *any* amount of signal reversal (change of direction: increasing vs. decreasing) will cause the valve to move slightly.

Compare the following transfer function graphs to understand the difference between hysteresis and dead band:

Ideal instrument response
(no hysteresis or dead band)

Dead band:
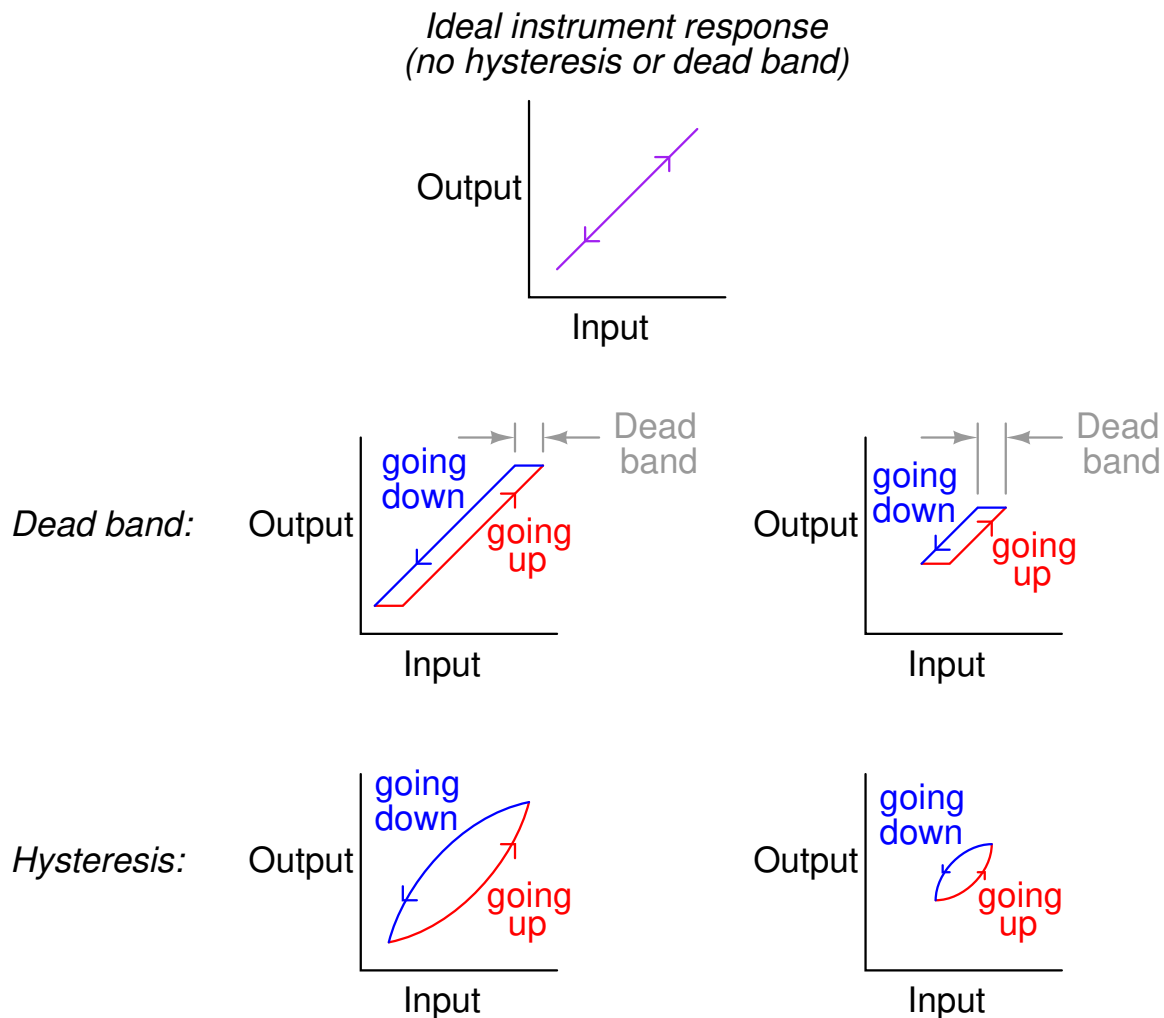
Hysteresis:

Both dead band and hysteresis are characteristically mechanical phenomena. Electronic circuits rarely exhibit such "artifacts" of measurement or control. Dead band and hysteresis are more often found together than separately in any instrument.

Interestingly, both effects are present in magnetic circuits. The magnetization curves for typical transformer core steels and irons are classic examples of hysteresis, whereas the magnetization curve for ferrite (in the saturation region) is quite close to being a true representation of deadband.

Svar 14

During regular operation:

- Open valves: 2, 4, 5, and 8

- Shut valves: 1, 3, 6, 7, and 9

Procedure to apply an LRV test pressure to the transmitter:

- Shut valves 2 and 4

- Open valves 1 and 6

- Inspect wet-leg liquid level (re-fill if necessary)

- Crack valve 4 open until liquid overflows out of LRV standpipe, then shut

- *The transmitter will now be sensing LRV pressure*

Svar 15

I'll answer the question with a scenario of my own: suppose it is discovered that some patients suffered complications after taking drugs manufactured by this company, and that the particular batch of suspect drugs were processed in this very same vessel about 6 months ago? Now imagine that this temperature recording instrument gets routinely calibrated once a month. See the problem?

Svar 16

Simply setting the LRV and URV values is not actually *calibrating* the transmitter to accurately correspond to reality. If this concept is hard to grasp, imagine a transmitter whose LRV and URV values are set perfectly, and whose DAC is calibrated just right, but whose ADC suffers from a zero shift. The microprocessor will "think" the pressure is something different from what it really is, and it will output an incorrect (zero-shifted) milliamp signal as a result.

In order to perform a sensor trim, you must connect a known pressure source (a *standard*) to the transmitter's input port and correlate that standard pressure to the pressure value registered by the microprocessor. When trimming the output, you must connect a precise milli-ammeter in series with the transmitter's output current to correlate the intended current signal of the microprocessor to the actual current.

Svar 17

Svar 18

The problem lies with the DCS: to be specific, someone has configured square-root characterization in it as well as within the transmitter!

Svar 19

The calibration error lies either with the transmitter, the impulse lines (unequal fluid heights inside), or with the orifice plate itself. The transmitter does have square-root characterization enabled.

A good "next step" would be to block and equalize the transmitter manifold to check what its PV and AO parameters register with no applied differential pressure.

Svar 20

This is a graded question – no answers or hints given!

Svar 21

Svar 22

This is a graded question – no answers or hints given!

Svar 23

Svar 24

Partial answer:

Input voltage (volts)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
1.6	32	1310 or 1311	
	73.8	3022	
	40		666
3.18			A2F

Svar 25

Input voltage (volts)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
0	0	0	000
2.5	25	1023 or 1024	3FF or 400
5.0	50	2047 or 2048	7FF or 800
7.5	75	3071 or 3072	BFF or C00
10	100	4095	FFF

Svar 26

Input voltage (volts)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
0	0	0	0000
2.5	25	16383 or 16384	3FFF or 4000
5.0	50	32767 or 32768	7FFF or 8000
7.5	75	49151 or 49152	BFFF or C000
10	100	65535	FFFF

Svar 27

Input pressure (PSI)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
0	0	0	000
27	36	5897 or 5898	1709 or 170A
46.5	62	10157 or 10158	27AD or 27AE
66.75	89	14580 or 14581	38F4 or 38F5
71.25	95	15563 or 15564	3CCB or 3CCC

Svar 28

This is a graded question – no answers or hints given!

Svar 29

Input level (inches)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
36.5	11	112 or 113	070 or 071
62.0	28	286 or 287	11E or 11F
102.5	55	562 or 563	232 or 233
129.5	73	746 or 747	2EA or 2EB
158.0	92	941 or 942	3AD or 3AE

Svar 30

- Formula for cell `R1C4`: `ROUND((R2C1 / 5) * 255)`

- Formula for cell `R2C4`: `DEC2BIN(R1C4)`

- Formula for cell `R3C4`: `DEC2HEX(R1C4)`

Svar 31

This is a graded question – no answers or hints given!

Svar 32

Flow rate (GPM)	Percent of max. flow (%)	Orifice ΔP ("W.C.)	FT output signal (PSI)	FY output signal (PSI)	FI indication (GPM)
0	0	0	3	3	0
40	10	1.25	3.12	4.2	40
100	25	7.81	3.75	6	100
200	50	31.25	6	9	200
300	75	70.31	9.75	12	300
360	90	101.25	12.72	13.8	360
400	100	125	15	15	400

Svar 33

Partial answer:

Input current (mA)	Displayed flow (GPM)
4	0
6	
9.3	402.9
13	525
14.8	
20	

Svar 34

This is a graded question – no answers or hints given!

Svar 35

Input current (mA)	Percent of range (%)	Output pressure (PSI)
4	0	3
5.6	10	4.2
7.2	20	5.4
8	25	6
8.8	30	6.6
10.4	40	7.8
12	50	9
13.6	60	10.2
15.2	70	11.4
16	75	12
16.8	80	12.6
18.4	90	13.8
20	100	15

Follow-up question: explain the procedure for starting with a current value in milliamps and calculating the equivalent percentage.

Svar 36

Here are two possible formulae for entry into cell R2C5:

```
= ((R2C1 - 4) / 16) * 12 + 3
```

```
= R2C3 * 12 + 3
```

One very practical use for this type of spreadsheet program is to create practice problems for yourself, so that you may practice instrument input/output range calculations.

Svar 37

This is a graded question – no answers or hints given!

Measured level (inches)	Percent of span (%)	Output signal (mA)
47	20	7.2
44.38	12.5	6
66.25	75	16
60	57.14	13.14
64.28	69.38	15.1
51.9	34	9.44

Svar 39

Partial answer:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
0	0				
	10				
	25	81.31	8		
	50				12.08
	75				
	90			18.32	
18	100	325.24			

Svar 40

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
8	0	156	3	2.88	3.12
8.4	10	160.8	4.2	4.08	4.32
9	25	168	6	5.88	6.12
10	50	180	9	8.88	9.12
11	75	192	12	11.88	12.12
11.6	90	199.2	13.8	13.68	13.92
12	100	204	15	14.88	15.12

Svar 41

Partial answer:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10			5.568	
	25	-82.28			
5.5	50				
	75		16		
	90				
	100	$+12.87$			

Svar 42

Process level (in)	Percent of span (%)	Differential pressure ("W.C.)	Output signal ideal (PSI)	Output signal min. (PSI)	Output signal max. (PSI)
0	0	-64	6	5.88	6.12
12.5	25	-51.5	12	11.88	12.12
25	50	-39	18	17.88	18.12
37.5	75	-26.5	24	23.88	24.12
50	100	-14	30	29.88	30.12

Svar 43

Partial answer:

Interface level (in)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
0	0	28.83		3.84	
	10		5.6		5.76
2.75	25	29.71		7.84	
	50		12		12.16
	75	31.48		15.84	
9.9	90		18.4		18.56
	100		20	19.84	

Svar 44

Input signal (PSI)	Percent of input span (%)	Percent of output span (%)	Output signal (PSI)
5	16.67	40.82	7.899
13	**83.33**	**91.29**	**13.95**
9	50	70.71	11.49
6.6	30	54.77	9.573
10.68	64	80	12.6
3.27	**2.25**	15	**4.8**
4.333	11.11	33.33	7
9.75	56.25	75	12

Values shown in bold-faced type are those given to students in the "Answer" section.

Svar 45

This is a graded question – no answers or hints given!

Svar 46

This is a graded question – no answers or hints given!

Svar 47

Partial answer:

Input pressure applied (PSI)	Percent of span (%)	Output signal (mA)
0	14.29	6.286
-5		
		12
32	60	13.6
	40	
	22	

Svar 48

Input pressure applied ("W.C.)	Percent of span (%)	Output signal (PSI)
0	50	9
−30	35	7.2
−16.67	41.67	8
66.67	83.33	13
30	65	10.8
−80	10	4.2

Svar 49

Input pressure applied (PSI)	Percent of span (%)	Output signal *ideal* (PSI)	Output signal *low* (PSI)	Output signal *high* (PSI)
0	0	3	2.94	3.06
50	25	6	5.94	6.06
100	50	9	8.94	9.06
150	75	12	11.94	12.06
200	100	15	14.94	15.06

Given the tolerance of ± 0.5% of the 200" span (± 1"), the actual process pressure could be as low as 152 "W.C. or as high as 154 "W.C.

Svar 50

Input pressure applied (" W.C.)	Percent of span (%)	Output signal *ideal* (mA)	Output signal *low* (mA)	Output signal *high* (mA)
50 L	0	4	3.984	4.016
37.5 H	25	8	7.984	8.016
125 H	50	12	11.984	12.016
212.5 H	75	16	15.984	16.016
350 H	100	20	19.984	20.016

Given the tolerance of ± 0.1% of the 350" span (± 0.35"), the actual process pressure could be as low as 209.65 "W.C. or as high as 210.35 "W.C.

Svar 51

Partial answer:

Input pressure (" W.C.)	Output current (mA)
0	
45	12.76
75	
90	
110	17.70
150	20

Svar 52

Shaft speed (RPM)	Output voltage (volts DC)
100	0.67
350	2.3
500	3.3
750	5.0
890	5.9
975	6.5
1230	8.2
1410	9.4
1500	10.00

Svar 53

Measured temp (^{o}F)	Percent of span (%)	Output signal (mA)
120	86.96	17.91
-45	15.22	6.435
16.6	42	10.72
-22.5	25	8
-29.69	21.88	7.5
47.94	55.63	12.9

Measured flow (l/m)	Pickup signal frequency (Hz)	Percent of output span (%)	Output signal (mA)
250	412.5	50	12
412	679.8	82.4	17.18
184.8	305	36.97	9.915
472.7	780	94.55	19.13
315	519.8	63	14.08
245	404.3	49	11.84
187.5	309.4	37.5	10
375	618.8	75	16

$$Q = kf$$

Where,
f = Frequency in Hertz (pulses per second)
k = Calibration factor in liter per pulse
Q = Volumetric flow rate in liter per second

$$Q = \frac{kf}{60}$$

Where,
f = Frequency in Hertz (pulses per second)
k = Calibration factor in pulses per gallon
Q = Volumetric flow rate in gallons per minute

Simulated flow rate (GPM)	Input frequency applied (Hz)	Percent of span (%)	Output signal (mA)
97	**32.33**	**16.17**	**6.587**
150	**50**	25	**8**
360	**120**	60	**13.6**
400	**133.3**	**66.6**	**14.67**

- **Pressure gauge**

- LRV = 0 PSI

- URV = 100 PSI

- Test pressure = 65 PSI

- Instrument indication = 67 PSI

- Error = *+2* % of span

- **Weigh scale**

- LRV = 0 pounds

- URV = 40,000 pounds

- Test weight = 10,000 pounds

- Instrument indication = 9,995 pounds

- Error = *-0.0125* % of span

- **Thermometer**

- LRV = -40°F

- URV = 250°F

- Test temperature = 70°F

- Instrument indication = 68°F

- Error = *-0.69* % of span

- **pH analyzer**

- LRV = 4 pH

- URV = 10 pH

- Test buffer solution = 7.04 pH

- Instrument indication = 7.13 pH

- Error = *+1.5* % of span

Svar 57

± 0.064 mA

Svar 58

This is a graded question – no answers or hints given!

Svar 59

Ideally, the secondary piston's position will have *no effect* on the oil pressure sent to the gauge. Consequently, the gauge indication should not change.

Svar 60

(1) The accuracy of a deadweight tester is fixed by three fundamental variables, all of which are quite constant, two of which can be manufactured to highly accurate specifications, and the third being a constant of nature:

- The mass of the calibration weights

- The area of the primary piston

- The gravity of the Earth

(2) If a deadweight is not level, the force generated by the precision weights will not be parallel to the primary piston's axis of travel, meaning that the piston will not support their full weight.

(3) Entrapped air will make the piston's motion "springy" rather than solid and secure.

(4) Spinning the primary piston eliminates static friction, leaving only dynamic friction (which is much less) to interfere with gravity's force on the primary piston.

Svar 61

We cannot tell exactly where the problem is, but we know it must be either in the receiver gauge or in the panel-mounted indicator (assuming only one fault in the system).

One test would be to block and equalize the DP transmitter's manifold, to see which indicator goes closest to zero. Chances are, the error is (at least) a zero shift, and as such should reveal itself in this test. Whichever indicator goes exactly to zero during this test is good; whichever one reads some non-zero value during this test is in error.

Another test would be to use a pressure gauge to measure the 3-15 PSI pneumatic signal coming from the transmitter. If the pressure is 5.78 PSI, the receiver gauge is good and the panel-mounted indicator must be in error. If the pressure is 6.05 PSI, the receiver gauge is in error and the panel-mounted indicator is good.