وزارة التعليم العالي والبحث العلمي
الجامعة التقنية الشمالية
المعهد التقني/كركوك

الحقيبة التعليمية

القسم العلمي:
تقنيات الصناعات الكيمياوية

اسم المقرر:

القياسات والسيطرة

المرحلة / المستوى: الثاني

الفصل الدراسي: الاول

السنة الدراسية:٢٠٢٣/٢٠٢٤

معلومات عامة

اسم المقرر:	القياسات والسيطرة
القسم:	تقنيات الصناعات الكيمياوية
الكلية:	المعهد التقني كركوك
المرحلة / المستوى	الثاني / الثانية
الفصل الدراسي:	الاول
عدد الساعات الاسبوعية:	نظري ٢ عملي ٢
عدد الوحدات الدراسية:	٤ وحدات
الرمز:	1CT214
نوع المادة	نظري ٢ عملي ٢ كلهما ٤
هل يتوفر نظير للمقرر في الاقسام الاخرى	كلا
اسم المقرر النظير	/
القسم	/
رمز المقرر النظير	/
معلومات تدريسي المادة	
اسم مدرس (مدرسي) المقرر:	كازيوه فريق صديق
اللقب العلمي:	معاون مهندس
سنة الحصول على اللقب	٢٠٢٣
الشهادة :	بكالوريوس
سنة الحصول على الشهادة	٢٠١١
عدد سنوات الخبرة (تدريس)	١ سنة

الاهداف العامة

الهدف العام : تعريف الطالب على الاجهزة الكهربائية المستخدمة في العمليات التكنولوجية والصناعات الكيمياوية وكذلك كيفية قياس المتغيرات والسيطرة عليها واعطاء فكرة عملية عن الاجهزة الكهربائية واجهزة القياس .

الأهداف الخاصة

الهدف الخاص : توسيع مدى ادراك الطالب لاستخدام الاجهزة وكيفية التعامل بها والسيطرة على المتغيرات الكيمياوية . وتوسيع معلوماتهم النظرية .

الأهداف السلوكية او نواتج التعلم

الأهداف السلوكية او مخرجات التعليم الأساسية		
ت	تفصيل الهدف السلوكي او مخرج التعليم	آلية التقييم
1	توسيع مدى ادراك الطالب لاستخدام الاجهزة	لمعرفة الأجهزة
2	كيفية قياس المتغيرات والسيطرة عليها واعطاء فكرة عملية عن الاجهزة الكهربائية واجهزة القياس	لادراك نوع القياس

أساليب التدريس (حدد مجموعة متنوعة من أساليب التدريس لتناسب احتياجات الطلاب ومحتوى المقرر)

الاسلوب او الطريقة	مبررات الاختيار
١. اسلوب محاضرة طويلة (اسلوب سرد وتلقين المعلومة مع الاسئلة والاجوبة	لتلقين معلومات جديدة على مجموعة من الطلبة في وقت محدد
٢.اسلوب محاضرة نقاشيةاعطاء فرصة مشاركة للطالب لطرح الاسئلة في اذهانهم	لاعادة الجزء غير المفهوم من المحاضرة للطالب وتقوية الثقة لدى الطالب للمشاركة
٣.اسلوب طرح موضوع او مشكلة وحلها	للحث على مشاركة اكبر عدد من الطلبة لترسيخ الفكرة لديهم
٤.اسلوب عصف الذهن	تعلم نشط لوضع ذهن الطلبة في حالة من الجاهزية والترقب

الفصل الاول من المحتوى العلمي						
عنوان الفصل	الوقت					
التوزيع الزمني	النظري	العملي	العنوان	طريقة التدريس	التقنيات	طرق القياس
الأسبوع الأول	٢	٢	مقدمة عن المقرر، أهداف التعلم، محتوى المقرر	محاضرة شفوية	عرض تقديمي، شرح، أسئلة وأجوبة, مناقشة	أسئلة واجوبة
الأسبوع الأول			Purposes of Measurements and Control technology, Used terms			امتحان يومي
الاسبوع الثاني	٢	٢	Errors, Accuracy and Measurement principles		اسئلة واجوبة شفهية	امتحان يومي
				محاضرة		
الأسبوع الثالث	٢	٢	Signal transmitting, Pointing and Recording instruments, the Units			
						مراجعة المواضيع
				محاضرة	اسئلة واجوبة تحريرية	

الفصل الثاني							
عنوان الفصل	الوقت						
التوزيع الزمني	النظري	العملي	العنوان الفرعي		طريقة التدريس	التقنيات	طرق القياس
				العناوين الفرعية	محاضرة شفوية	عرض تقديمي، شرح، أسئلة وأجوبة, مناقشة	
الأسبوع الرابع	٢	٢	Principals of Electricity, Electrical energy and Electrical power, Ohm s Law,Resistors,Capacitors		محاضرة	اسئلة واجوبة	
	٢	٢			محاضرة شفوية		امتحان يومي
الأسبوع الخامس			Magnetism, Electrical Magnetism, Direct current, Alternating current, Inductors		محاضرة		
	٢	٢			محاضرة شفوية	امتحان يومي	
							واجب محاضرة السابقة

الفصل الثالث							
عنوان الفصل	الوقت						
التوزيع الزمني	نظري	عملي	العنوان الفرعي		طريقة التدريس	التقنيات	طرق القياس
الأسبوع.....				العناوين الفرعية	محاضرة	عرض تقديمي، شرح، أسئلة وأجوبة, مناقشة	مناقشة اراء الطلبة
الأسبوع السادس	٢	٢	Electric circuits, Kirchhoffs Law			شرح شفوي مع استخدام السبورة	
الأسبوع السابع	٢	٢				تقارير/استخدام السبورة	امتحان يومي
الأسبوع الثامن	٢	٢			حل المسائل	اسئلة واجوبة	إعطاء واجب
						استخدام السبورة	

الفصل الرابع (من المحتوى العلمي)							
عنوان الفصل	الوقت						
التوزيع الزمني	نظري	عملي			طريقة التدريس	التقنيات	طرق القياس
الأسبوع			العناوين الرئيسية	العناوين الفرعية	محاضرة	عرض تقديمي، شرح، أسئلة وأجوبة, مناقشة	
الأسبوع التاسع	٢	٢	Pressure measurement, Electrical methods				
الأسبوع العاشر	٢	٢					
الأسبوع الحادي عشر	٢	٢			محاضرة على السبورة	تقارير/استخدام السبورة	امتحان يومي
الاسبوع الثاني عشر	٢	٢					
الاسبوع الثالث عشر	٢	٢					
الاسبوع الرابع عشر	٢	٢	Temperature Measurement, Rotating methods		محاضرة	شرح شفوي مع استخدام السبورة	امتحان يومي
الاسبوع الخامس عشر			Measurement of Volumes, Mass and Flow Rates		محاضرة	اسئلة واجوبة	امتحان يومي
	٢	٢					

المحتوى العلمي

خارطة القياس المعتمدة

المحتوى التعليمي	عناوين الفصول	الأهمية النسبية	الأهداف السلوكية					عدد الفقرات
			المعرفة	الفهم	التطبيق	التحليل	التقييم	
			النسبة ٢٠٪	١٠٪	٢٥٪	١٥٪	٣٠٪	
الفصل الاول	Purposes of Measurements and Control technology, Used terms	٠،١٧٪	١	١	١،٢	١	١،٢٢	٤
الفصل الثاني	Principals of Electricity, Electrical energy and Electrical power, Ohm s Law,Resistors,Capacitors	٠،١١٪	١	١	١،٥	١	١،٧٨	٦
الفصل الثالث	Magnetism, Electrical Magnetism, Direct current, Alternating current, Inductors	٠،١١٪	٢	١	١،٥	١	٢،٠٦	٧
الفصل الرابع	Pressure measurement, Electrical methods	٠،١٨٪	٢	١	٢،٢	١	٢،٢٢	٩
المجموع		١٠٠	١٠	٨	١٢	٨	١٢	**٥٠**

المحتويات (لكل فصل في المقرر)

رقم المحاضرة:	١
عنوان المحاضرة:	Purposes of Measurements and Control technology, Used terms
اسـم المدرس:	كازيوه فريق صديق
الفئة المستهدفة :	طلبة المعهد التقني /قسم تقنيات الصناعات الكيمياوية
الهدف العام من المحاضرة :	طرق السيطرة وقياس الاجهزة
الأهداف السلوكية او مخرجات التعلم:	١- فهم المبادئ الأساسية لتشغيل الأجهزة ٢- كيفية السيطرة على الاجهزة
استراتيجيات التيسير المستخدمة	١- التعلم التفاعلي: تشجيع النقاشات والأسئلة لتحفيز التفكير. ٢- العروض العملية: تقديم تجارب حية أو عروض توضيحية للمفاهيم. ٣- التقييم المستمر: تقديم اختبارات قصيرة أو أنشطة تقييمية خلال الدروس. ٤- التغذية الراجعة الفورية: إعطاء ملاحظات مباشرة للطلاب لتحسين الأداء. ٥- التطبيق العملي: تنفيذ مشاريع أو تمارين عملية لمحاكاة الواقع.
المهارات المكتسبة	إدراك الطالب لاستخدام الاجهزة
طرق القياس المعتمدة	

٤ ـ الاسئلة القبلية

Q/ Measurement: Involves using an instrument as a physical amount (mass, temperature, current) to determine a quantity or variable.

٥- المحتوى العلمي

محتويات الفصل

Measurement & Control

Lecture One

Purposes Of Measurement and Control Technology, Used terms

Measurement: Involves using an instrument as a physical amount (mass, temperature, current) to determine a quantity or variable.
Measurement work employs a number of terms which should be defined here:

1. **Instrument**: a device which used to determine the quantity or variable.
2. **Accuracy**: closeness which an instrument reading approaches the value of variable being measured.
3. **Precision**: It gives a fixed value of variable. It measures the difference degree from one to another.
4. **Sensitivity**: The ratio of output signal or response of the instrument to a change of input or measured variable.
5. **Resolution**: The smallest change in measured value to which the instrument will respond.
6. **Error:** The deviation from true value of the measured variable.

The reasons of error:

1. In perfect of equipment
2. Measuring method

3. Influence of circumstance (temperature, pressure)
4. Person using the equipment.
5. Time change of error.

٦- الاسئلة البعدية

Q1/ what is the measurement ?

Q2/ what is the control?

رقم المحاضرة:	٢
عنوان المحاضرة:	Errors, Accuracy and Measurement principles
اسـم المدرس:	كازيوه فريق صديق
الفئة المستهدفة :	طلبة المعهد التقني /قسم تقنيات الصناعات الكيمياوية
الهدف العام من المحاضرة :	معرفةالأخطاء في الاجهزة
الأهداف السلوكية او مخرجات التعلم:	١- فهم المبادئ الأساسية لتشغيل الأجهزة واكتشاف اخطاء ٢- كيفية تجنب وحساب الاخطاء
استراتيجيات التيسير المستخدمة	١- التعلم التفاعلي: تشجيع النقاشات والأسئلة لتحفيز التفكير. ٢- العروض العملية: تقديم تجارب حية أو عروض توضيحية للمفاهيم. ٣- التقييم المستمر: تقديم اختبارات قصيرة أو أنشطة تقييمية خلال الدروس. ٤- التغذية الراجعة الفورية: إعطاء ملاحظات مباشرة للطلاب لتحسين الأداء. ٥- التطبيق العملي: تنفيذ مشاريع أو تمارين عملية لمحاكاة الواقع.
المهارات المكتسبة	معرفة نسبة أخطاء في الاجهزة
طرق القياس المعتمدة	

٤ ـ الاسئلة القبلية

Q/ What are the measuring errors ?

٥ـ المحتوى العلمي

محتويات الفصل

Types of Errors:

1. Absolute Error

$_0 X \; X \; X_{abs} \; \Delta = -$

2

Where:

X_{abs}: absolute error.

X : reading value.

X_0: Actual value (value of measured amount).

2. Relative Error: It is the relation between absolute error and the value of reading x

$\times 100$

Δ

$\Delta =$

X

$Xabs$

X_{rel}

3. **Reduced Error:** It is the relation of maximum absolute error to the

measurement range.

100

max min

( )max Δ = × –

Δ

x x

xabs

red X

Example 1:

An equipment measure the temperature from 0°C to 400 °C and the highest value of absolute error is 10 °C. Find

1. Reduced error , Relative error for 50 °C
2. Reduced error , Relative error for 60 °C
3. Comment the results.

Solution:

100

max min

( )max Δ = × –

Δ

x x

xabs

red X

$100\ 2.5\%$ $400\ 0$

$= 10 \times = -$

3

$\times 100$

Δ

$\Delta =$

X

$Xabs$

X_{rel}

$100 = 20\%$

٦- الاسئلة البعدية

Q/ what is the reasons of errors?

رقم المحاضرة:	٣
عنوان المحاضرة:	Signal transmitting, Pointing and Recording instruments, the Units
اسـم المدرس:	كازيوه فريق صديق
الفئة المستهدفة :	طلبة المعهد التقني /قسم تقنيات الصناعات الكيمياوية
الهدف العام من المحاضرة :	معرفة أجهزة ارسال اشارة
الأهداف السلوكية او مخرجات التعلم:	١- تعلم كيفية ارسال اشارة ٢- كيفية توجيه إشارة وتسجيلها
استراتيجيات التيسير المستخدمة	١- التعلم التفاعلي: تشجيع النقاشات والأسئلة لتحفيز التفكير. ٢- العروض العملية: تقديم تجارب حية أو عروض توضيحية للمفاهيم. ٣- التقييم المستمر: تقديم اختبارات قصيرة أو أنشطة تقييمية خلال الدروس. ٤- التغذية الراجعة الفورية: إعطاء ملاحظات مباشرة للطلاب لتحسين الأداء. ٥- التطبيق العملي: تنفيذ مشاريع أو تمارين عملية لمحاكاة الواقع.
المهارات المكتسبة	معرفة استخدام إشارات الاجهزة
طرق القياس المعتمدة	

٤ ـ الاسئلة القبلية

Q/ who to record the signal?

٥- المحتوى العلمي

محتويات الفصل

Signal transmitting:

Signal transmitting is important and used for pointing and recording and controlling where the information moves from sensor to distance between meters into many kilometers. There are **two ways** for signal transmitting:

1. Electrical signal transmitting.
2. Pneumatically signal transmitting.

Grading of reading instrument:

There are four types of grading are:

1. Number c
2. Linear
3. Central scale
4. Non-central scale

٦- الاسئلة البعدية

رقم المحاضرة:	٤
عنوان المحاضرة:	Principals of Electricity, Electrical energy and Electrical Law,Resistors,Capacitors power, Ohm s
اسـم المدرس:	كازيوه فريق صديق
الفئة المستهدفة :	طلبة المعهد التقني /قسم تقنيات الصناعات الكيمياوية
الهدف العام من المحاضرة :	معرفة المبدا الأساسي للكهرباء
الأهداف السلوكية او مخرجات التعلم:	١- معرفة كيفية حساب الطاقة الكهربائية ٢- كيفية حساب المقاومات والمتسعات في الدوائر
استراتيجيات التيسير المستخدمة	١- التعلم التفاعلي: تشجيع النقاشات والأسئلة لتحفيز التفكير. ٢- العروض العملية: تقديم تجارب حية أو عروض توضيحية للمفاهيم. ٣- التقييم المستمر: تقديم اختبارات قصيرة أو أنشطة تقييمية خلال الدروس. ٤- التغذية الراجعة الفورية: إعطاء ملاحظات مباشرة للطلاب لتحسين الأداء. ٥- التطبيق العملي: تنفيذ مشاريع أو تمارين عملية لمحاكاة الواقع.
المهارات المكتسبة	معرفة استخدام المقاومات والمتسعات حسب الدوائر
طرق القياس المعتمدة	

٤ - الاسئلة القبلية

Q/ what is the electrical energy?

Principles Of Electricity:
Most of measured and controlled amount in petroleum and chemical industries will be measured and controlled by using electrical methods. The nonelectrical amounts will be converted into electrical amount such as current, resistance, and potential.

Electrical Energy:
It is the amount of work required to maintain a current (1 A) flow through a resistance R (Ω) for time (second).

$$w = E\, I\, t$$

Where:

W: electrical energy (W.s)

6

E: potential energy (V)

I: current (A)

t: time (s)

When **E= I R** then

$$w\ I\ Rt\ {}_{2} =$$

Example:
A small electric coil in a torch has a current 0.2 A for about 2 hours. Find the total electric energy when E= 1.5 volt.

Solution:

$w = E\,I\,t$

$w = 1.5*0.2*2*3600 = 2160 W.s$

Electrical Power:

It is the electric energy divided by time.

t

$P = w$

Where:

P: electrical power (watt)

w: electrical energy (watt-second)

t: time (second)

When **E= I R** and **w= E I t** produce

R

$P\ I\ R\ or\ P\ V$

$2\ 2 = =$

Note ١ : اذا جاء في الامتحان الباور بوحداث القدرة الحصانيت فيجب ان نعمل على تحويل القدرة الحصانية الى الواط.

٦- الاسئلة البعدية

رقم المحاضرة:	٥
عنوان المحاضرة:	Magnetism, Electrical Magnetism, Direct current, Alternating current, Inductors
اسـم المدرس:	كازيوه فريق صديق

الفئة المستهدفة :	طلبة المعهد التقني /قسم تقنيات الصناعات الكيمياوية
الهدف العام من المحاضرة :	تعرف الطالب على المغناطيسية الكهربائية
الأهداف السلوكية او مخرجات التعلم:	كيفية حساب التيار المستمر والتيار المتناوب .
استراتيجيات التيسير المستخدمة	١- التعلم التفاعلي: تشجيع النقاشات والأسئلة لتحفيز التفكير. ٢- العروض العملية: تقديم تجارب حية أو عروض توضيحية للمفاهيم. ٣- التقييم المستمر: تقديم اختبارات قصيرة أو أنشطة تقييمية خلال الدروس. ٤- التغذية الراجعة الفورية: إعطاء ملاحظات مباشرة للطلاب لتحسين الأداء. ٥- التطبيق العملي: تنفيذ مشاريع أو تمارين عملية لمحاكاة الواقع.
المهارات المكتسبة	تعلم كيفية استخدام العلاقة بين المغناطيسية والكهربائية
طرق القياس المعتمدة	

٤ - الاسئلة القبلية

٥- المحتوى العلمي

محتويات الفصل

Magnetism and electro magnetism:

The phenomena of magnetism and electro magnetism are dependent upon a certain property of the medium is that called **(permeability).**

Every medium have two permeability's:

1. Absolute permeability μ **.**

2. Relative permeability μ_r .

For measuring relative permeability, vacuum or free space is chosen are reference medium. It is allowed on absolute permeability of $\mu_0 = 4\pi * 10^{-7}$ $\frac{H}{m}$

For obviously, Relative per of vacuum with reference to its self unity. Hence for free space

$\mu_0 = 4\pi*10^{-7}$

m

H

$\mu_r = 1$

Know take any medium other free space if its relative permeability as compared vacuum μ_r, then its absolute permeability μ_0 is given by $\mu_r\ \mu\ *\mu_0 =$

Magnetic Material

Material can be classified according to the natural f its relative permeability. In general the material either magnetic or non-magnetic depends upon the value of μ_r .

In general for magnetic material $\mu_r >= 100$

In general for non-magnetic material $\mu_r = 1$

Magnetic Field

In the region of surrounding a permanent magnet there exists a magnetic field, which represented by magnetic flux line ϕ .

26

Inductors

In connecting coil made of good conductor as copper across direct current source, this action will produce electrical current. Its value is constant proportional to the electro motive force value of source and wire resistance as any resistor.

$_t e \; N \; \Delta$

$\Delta = - \phi$

Where:

e: electro motive force.

N: turn number of coil.

$ratechangeof\,flux \; _t : \; \Delta$

$\Delta\phi$

.

Inductance: is the ability of conductor to produce induced voltage when the current varies. Its symbol (L) and its unit (**Henry**).

I

$L \; _{e\, t} \Delta$

$= \; {}^*\Delta$

If coil supplied with alternative voltage so the current change alternatively and produce resistance of X_L which called inductive reactance.

$X f L \; _L = 2\Pi$

$X L \; _L = \omega$

Where: f: frequency (Hz) and ω : angular velocity

To calculate the **energy stored** in an inductors

2

2

$W = {}_1 LI$

Reluctance: (R): The resistance of setting up of magnetic flux lines in the material.

A

$R \; L \, \mu =$

Its unit is **(rels or At/Wb)**.

But the resistance of material to the flow of change current is determined by:

$_A R = \rho \; \ell$

27

Flux Density: The number of flux lines per unit area.

$_A B \; \phi =$

Where

B: flux density **(Tesla).**

ϕ :Magnetic flux (wb).

A: Area (m_2).

If area makes angle with the flux

θ

ϕ

$A \sin B =$

Permeability: The flux density (B) is directly proportional on field intensity (H) and the proportional constant called permeability.

$_r \mu \; \mu \; \mu \; _0 =$

Where:

$_0\mu =$ is the permeability of absolute vacuum.

$_r\mu =$ is the relative permeability of the medium.

The flux density and the magnetizing force are related by the following equation.

$B \; H$

$B \; H$

$_r\mu \; \mu$

μ

$_0 =$

$=$

1

$4 *10 (/) \; _7$

$_0$

$=$

$= \Pi \; _-$

for air

$H \; m$

$_r\mu$

μ

This equation indicates that for a particular magnetizing force, the greater the permeability, the greater will be the induced flux density..

Important terms which specially used in inductors

1. Magnetic Motive force

$F = N I$

The unit of F is (At).

28

2. Field Intensity (Magnetizing force): it is the magnetic motive force per unit length.

ℓ ℓ

$H = F = N I$

The unit of H is (At/m).

Note1: It is interesting to realize that the magnetizing force (H) is independent on the type of core material; it is determined solely by number of turns, the current, and the length of the core.

Note2: The applied magnetizing force has a pronounced effect on the resulting permeability of a magnetic material. As the magnetizing force increases, the permeability rises to a maximum and then drops to a minimum as shown in figure below.

M

H

Sh ee t stee l C ast

st ee l

Hysteresis

29

Compare between electric circuit and magnetic circuit

Electric circuit Magnetic circuit

الجامعة التقنية الشمالية

Voltage V

$V=V_1+V_2+V_3$

Magnetic motive force F

$F=F_1+F_2+F_3$

Conductivity

ρ

$X = 1$

Permeability

$_r\mu\ \mu_0$

Electric resistance

$_{XA} R = 1$

$R=R_1+R_2+R_3$

Magnetic resistance

$_rA$

$S\ _{\mu0\mu}$

$\ell =$

$S=S_1+S_2+S_3$

Electric Conductivity

R

1

Electric Conductivity

S

1

Current I Magnetic Flux ϕ

Current density B

$= I$

Flux density $_A B\ \phi =$

Ohms Law $_R$

$I = {}_V$ Ohms Law $_S$

$\phi = {}_F$

Example: Calculate the magnetizing force (H) which produce flux density B=0.001wb/m2.

Solution

$H\ At\ m$

H

r

B

79.6 /

4* *10 *1

0.001

7

0

= =

=

- Π

μ μ

31

Example: A coil with inductance (L=0.1 H) connected a cross voltage with frequency (f=50 Hz). Find the resistance of the coil and how much resistance will be when f=60 Hz.

Solution:

= = Ω

= = Ω

= Π

2*3.14*60*0.1 37.70

2*3.14*50*0.1 31.41

2

L

L

L

X

X

X f L

Example: An-magnetic ring has a mean diameter of (44.5 cm) and have a cross sectional area (12 cm2) is wound with a coil of 500 turn. Find the field intensity and the flux density when the current is 1 A through the coil.

Solution:

BA wb

B wb m

B H

H At m

H L N I

r

N I

4 4 6

7 4 2

0

44.5*10

500*1
4.496*10 *12*10 0.53*10
1* 4*3.14*10 *358 4.496*10 /
358 / 2
− − −
− −
= = =
= =
=
= = =
=
−
ϕ
μ μ
ℓ

Example: An iron ring has a mean circumferential length 100 cm and has a cross sectional area 100 cm2. It wound with coil of 200 turns. Find the current required to produce a flux 1 mwb. The relative permeability of iron is 500.

Solution:

$I\ Amp$

٦ـ الاسئلة البعدية

٦,٧,٨	رقم المحاضرة:
Electric circuits, Kirchhoff's Law	عنوان المحاضرة:

اسـم المدرس:	كازيوه فريق صديق
الفئة المستهدفة :	طلبة المعهد التقني /قسم تقنيات الصناعات الكيمياوية
الهدف العام من المحاضرة :	تعليم الطالب لحل الدوائر المعقدة
الأهداف السلوكية او مخرجات التعلم:	١-كيفية حساب التيار في الدوائر المعقدة ٢-كيفية حساب الفولطية في الدوائر المعقدة
استراتيجيات التيسير المستخدمة	١- التعلم التفاعلي: تشجيع النقاشات والأسئلة لتحفيز التفكير. ٢- العروض العملية: تقديم تجارب حية أو عروض توضيحية للمفاهيم. ٣- التقييم المستمر: تقديم اختبارات قصيرة أو أنشطة تقييمية خلال الدروس. ٤- التغذية الراجعة الفورية: إعطاء ملاحظات مباشرة للطلاب لتحسين الأداء. ٥- التطبيق العملي: تنفيذ مشاريع أو تمارين عملية لمحاكاة الواقع.
المهارات المكتسبة	تسهيل الطرق حل المسائل الحسابية
طرق القياس المعتمدة	

٤ ـ الاسئلة القبلية

٥- المحتوى العلمي

محتويات الفصل

Kirchhoff's Laws

➢Kirchhoff'sLawsforcurrentandvoltagelieattheheartofcircuitanalysis.

➢Kirchhoff'sLawsdescribecurrentinanodeandvoltagearoundaloop.Thesetwolawsarethefoundationofadvancedcircuitanalysis.

- Kirchhoff'sCircuitLawsallowustosolvecomplexcircuitproblemsbydefiningasetofbasicnet worklawsandtheoremsforthevoltagesandcurrentsaroundacircuit

Kirchhoff's Voltage Law (KVL)

Inanelectricalcircuit,theVoltageacrossaresistorisalwaystheoppositepolarityfromtheVoltag esource.ThismeansiftheVoltagesourceisapositivepolarity(+),theVoltagedropacrosstheresis torsinthatelectricalcircuitwillbeanegativepolarity(-).IftheVoltagesourceisanegativepolarity(-),theVoltagedropacrosstheresistorsin

Kirchhoff's Voltage Law (KVL)

Thesumofallthevoltagedropsaroundasingleclosedpathinacircuitisequaltothetotalsourcevolt ageinthatclosedpath.

$V1+V2+V3+V4=VS$

The algebraic sum of all voltage (both source & drops) around a closed path is zero.

$$VS-V1-V2-V3-V4=0$$

Node:-
anodeisajunction,connectionorterminalwithinacircuitweretwoormorecircuitelementsareconnectedorjoinedtogethergivingaconnectionpointbetweentwoormorebranches.Anodeisindicatedbyadot.

- **Branch:-**
abranchisasingleorgroupofcomponentssuchasresistorsorasourcewhichareconnectedbetweentwonodes.

- **Loop:-**
aloopisasimpleclosedpathinacircuitinwhichnocircuitelementornodeisencounteredmorethanonce.

Kirchhoff's Current Law (KCL)

- Thesumofthecurrentsintoanode(totalcurrentin)isequaltothesumofthecurrentsoutthatnode(totalcurrentout)

I5
I4
I3
I2
I1

$I1+I4+I5=I2+I3$

- Thealgebraicsumofallthecurrentsenteringandleavinganodeisequaltozero.

$I1+I4+I5-I2-I3=0$

Here,thethreecurrentsenteringthenode,I_1,I_4,I_5areallpositiveinvalueandthetwocurrentsleavingthenode,I_2andI_3arenegativeinvalue.

Determinethevaluesofthecurrentflowingthrougheachoftheresistorsandthevoltageacrosseachresistorsusing(KVL)&(KCL)

Example

Solution

$8-5I1-10I3=0$

Loop 1

$5I1+10I3=8$

1

Loop 2

$-10+10I3+6I2=0$

$6I2+10I3=10$

2

$I1+I2=I3$

$I1+I2-I3=0$

3

$I1+I2-I3=0$

3

$5I1+0I2+10I3=8$

1

$0I1+6I2+10I3=10$

2

$D=5010061011-1$

$X=80101061001-1$

$=5-6-10-00-10+100-6$

$=-80-60=-140$

$=8-6-10-0-10+0+1010-0$

$=-128+100=-28$

$Y=58100101010-1$

$Z=5080610110$

$=5-10-0-80-10+100-10$

$=-50+80-100=-70$

$=50-10-00-10+80-6$

$=-50-48=-98$

$I1=XD$

$I2=YD$

$I3=ZD$

$I1=-28-140$

$I1=0.2A$

$I5\Omega=0.2A$

$I2=-70-140$

$I2=0.5A$

$I6\Omega=0.5A$

$I3=-98-140$

$I3=0.7A$

$I10\Omega=0.7A$

$V5\Omega=1\text{V}$

$V6\Omega=3\text{V}$

$V10\Omega=7\text{V}$

٦ـ الاسئلة البعدية

رقم المحاضرة:	٩,١٠,١١,١٢,١٣
عنوان المحاضرة:	Pressure measurement, Electrical methods
اسـم المدرس:	كازيوه فريق صديق
الفئة المستهدفة :	طلبة المعهد التقني /قسم تقنيات الصناعات الكيمياوية
الهدف العام من المحاضرة :	تعليم الطالب لطرق قياس الضغط
الأهداف السلوكية او مخرجات التعلم:	١-كيفية قياس ضغط الاجهزة ٢- معرفة طرق الكهربائي لقياس الاجهزة
استراتيجيات التيسير المستخدمة	١- التعلم التفاعلي: تشجيع النقاشات والأسئلة لتحفيز التفكير. ٢- العروض العملية: تقديم تجارب حية أو عروض توضيحية للمفاهيم. ٣- التقييم المستمر: تقديم اختبارات قصيرة أو أنشطة تقييمية خلال الدروس. ٤- التغذية الراجعة الفورية: إعطاء ملاحظات مباشرة للطلاب لتحسين الأداء. ٥- التطبيق العملي: تنفيذ مشاريع أو تمارين عملية لمحاكاة الواقع.
المهارات المكتسبة	معرفة طبيعة الأجهزة بطريقة ادق
طرق القياس المعتمدة	

٤ ـ الاسئلة القبلية

Calculate the pressure detected by a U-tube manometer if the liquid in the manometer has a specific gravity of 2.95, and it is displaced 20 inches when pressure is applied.

٥- المحتوى العلمي

محتويات الفصل

Pressure Measurement

Introduction

This chapter will cover pressure gauges, types of process signal transmitters, electrical pressure sensors and some pressure transmitter applications. Pressure measurement is discussed first in this book because it is used to sense other process variables, such as level, temperature and flow.

A pressure sensor is used to convert pressure into a mechanical or electrical signal. This process variable is then used to indicate pressure or to generate a scaled transmitted signal that can be used to control a process. Before discussing pressure gauges, pressure sensors, and some pressure applications, we need to define pressure and other terms associated with pressure measurement.

Definition of Pressure

A major concern in process control applications is the measurement of fluid pressure. The term *fluid* means a substance that can flow; hence, the term applies to both liquids and gases. Both will occupy the container in which they are placed. However, if a liquid does not completely fill the container it will have a free liquid surface, whereas a gas will always fill the volume of a container. If a gas is confined in a container, its molecules strike the container walls. The collision of molecules against the walls results in a force against the surface area of the container. The pressure is equal to the force applied to the

walls divided by the area that is perpendicular to the force. For a liquid at rest, the pressure exerted by the fluid at any point is perpendicular to the boundary of the liquid. Pressure is defined as a force applied to, or distributed over, a surface area, or

(5-1)

where *P* is pressure, *F* is force, and *A* is area. The standard unit of pressure in the English or foot-pound-second (fps) system is pounds per square inch (psi), where the force is expressed in pounds and the area in square inches. This is the most common pressure unit encountered in process control applications and will be used extensively throughout this book. In the International System of Units (SI), the pressure units are Pascal (Pa) or Newton per square meter (N/m^2). Table 5-1 lists several pressure-unit conversion factors.

Pressure in a Fluid

In our basic definition of pressure, we neglected the weight and density of the fluid and assumed that the pressure was the same at all points. It is a familiar fact, however, that atmospheric pressure is greater at sea level than at mountain altitudes and that the pressure in a lake or in the ocean increases the greater the depth below the surface. Therefore, we must more clearly define pressure at *any point* as the ratio of the normal force ⊗*F* exerted on a small area ⊗*A* (including the point) as follows:

(5-2)

If the pressure is the same at all points of a finite plane surface that has area *A*, this equation reduces to Equation 5-1.

Table 5-1. Pressure-unit Conversion Factors

1 inches water (inH_2O) = 0.0360 psi = 0.0737 inches mercury (inHg)
1 foot water = 0.4320 psi = 0.8844 inHg
1 psi = 27.7417 inH_2O = 2.0441 inHg
1 kg/cm^2 = 14.22 psi = 98.067 kilopascals (kPa)
Note: All fluids at a temperature of 22°C.

P F

A

= ----

P ⊗*F*

⊗*A*

= --------

Let's find the general relation between the pressure at any point in a fluid in a gravitational field and the elevation of the point *y*. If the fluid is in equilibrium, every volume element is in equilibrium. Consider a section of a homogeneous fluid with density 〉 (rho) in the form of a thin slab, shown in Figure 5-1.

Since density is defined as mass (*m*) per unit volume (*V*) or 〉 = *m*/*V*, the mass of the thin slab is 〉 *A*⊗*y* and its weight (W) is 〉 *gA*⊗*y*. The force exerted on the element by the surrounding fluid is everywhere perpendicular to the surface. By symmetry, the sum of the horizontal forces on the slab's vertical sides is equal to zero. The upward force on its lower face is *PA*, the downward force on its upper face is (*P* + ⊗*P*)*A*, and the weight of the slab is 〉*gA*⊗*y*. Since the slab is in equilibrium, all three forces must equal zero, or:

Solving this equation for the change in pressure, ⊗*P*, gives us:

⊗*P* = –〉*g*⊗*y* (5-3)

Since density 〉 and gravity *g* are both positive numbers, it follows that a positive ⊗*y* (increase of elevation) is accompanied by a negative ⊗*P* (decrease of pressure). If P_1 and P_2 are the pressures at elevations y_1 and y_2 above some reference level (datum), then:

(5-4)

Figure 5-1. Forces on slab of fluid at equilibrium

PA

(P+⊗P)A

Fluid surface

Area (A)

⊗y

y

W

Slab of

Weight (W)

PA – (*P* + ⊗*P*)*A* – 〉*gA*⊗*y* = 0

$P_2 - P_1$ = –〉$g(y_2 - y_1)$

Let's apply this equation to a given point in the liquid of the open vessel shown in Figure 5-2.

Take point 1 at a given level, and let *P* represent the pressure at that point. Select point 2 at the top of the liquid in the tank, where the pressure is atmospheric pressure, represented by P_a. Then Equation 5-4 becomes the following:

(5-5)

And since $h = y_2 - y_1$, we obtain:

(5-6)

Equation 5-6 indicates that the shape of the open tank does not affect the pressure and that the pressure is influenced only by the depth (*h*) and the density (〉). This fact was recognized in 1653 by the French scientist Blaise Pascal (1623-1662) and is called Pascal's law. This law states that whenever an external pressure is applied to any confined fluid at rest, the pressure is increased at every point in the fluid by the amount of the external pressure.

Since water is the most common fluid encountered in process control, the pressure properties of water are important. Figure 5-3 shows water in a cubic foot container. The weight of this cubic foot (ft^3) of water is 62.3 lbs at 20°C, and this weight is exerted over the surface area of 1 ft^2, or 144 in^2. Since pres-

Figure 5-2. Pressure in a vessel open to atmosphere

Liquid Surface

y_1

y_2

2

$h = y_2 - y_1$

P_2

P_1 1
$P_a - P = -\rangle g(y_2 - y_1)$
$P = P_a + \rangle gh$

sure is defined as $P = F/A$ (Equation 5-1), the total pressure on the surface of 1 ft^2 is given by the following:
This means a 1-ft column of water exerts a pressure of 0.433 lb/in^2. Conversely, a pressure of 0.433 psi will cause a column of water to be raised 1 ft.
A practical application of Pascal's law is the hydraulic press shown in Figure 5-4. A small force (F_1) is applied to the small position (area A_1). The following relationship exists in the hydraulic press because, according to Pascal's law, the pressure at every point is equal:
Since:
and
then:
Figure 5-3. Cubic foot container of water
P F
A
---- 62.3 lbs
144 in^2
$= =$ ------------------- $= 0.433psi$
Water in container weighs 62.3 lbs at 20o C
12 in.
12 in.
12 in.
$P_1 = P_2$
P_1
F_1
A_1
= ------ P_2
F_2
A_2
= ------
F_1
A_1

F_2
A_2
= ------

So that:
(5-7)
The hydraulic press is a force amplifier where the gain is A_2/A_1.
The most common application of this principle is the hydraulic brake system in automobiles. It is also used very extensively in pneumatic and hydraulic instruments as well as in equipment used to amplify process signals.
Example 5-1 illustrates how the concept expressed by Pascal's law can be utilized in practical applications.

Pressure Exerted by Gases

Liquids conform to the shape of the vessel they are contained in and form a surface layer if the liquid does not fill the vessel. Gases, on the other hand, assume no definite shape. They will expand to fill the entire vessel that contains them. Therefore, a gas will exert an equal amount of pressure on all surfaces of the container. Two factors that affect the pressure that a gas exerts on the surface of the container are the volume of the vessel and the temperature of the gas. The relationship between the pressure (*P*) exerted by the gas and the volume (*V*) of the vessel is expressed by Boyle's law:

Figure 5-4. Hydraulic press

Supply

Port

P_2

P_1

Area 1 = A_1

Area 2 (A_2)

F_2

F_1

F_2

A_2

A_1

= ------F_1

(5-8)

where K is a constant, and the gas in the closed system is held at a constant temperature.

Boyle's law states that if temperature is held constant, the pressure exerted by the gas on the walls of a container varies inversely with the volume of the vessel. This means that if the volume of the container is decreased, the pressure exerted by the gas increases. Conversely, if the volume of the vessel is increased, the pressure exerted by the gas decreases. For example, suppose that the pressure exerted by a gas in a 2 ft^3 container is 10 psi. If the container size is increased to 4 ft^3, the pressure will decrease to 5 psi if the temperature of the gas is held constant. This relationship can be expressed mathematically as $P_1 \times V_1 = P_2 \times V_2$, where P_1 and V_1 are the initial pressure and volume of the gas, respectively, and P_2 and V_2 are the final pressure and volume. To find the final pressure (P_2) if the volume changes and the temperature remains constant, we use the following equation:

(5-9)

Example 5-2 illustrates the use of Boyle's Law.

EXAMPLE 5-1

Problem: Find the force F_2, given the following specification for the hydraulic press in Figure 5-4: A_1 = 0.5 in.^{2}, A_2 = 5 in.^{2}, and F_1 = 100 lbs.

Solution: Using Equation 5-7, we obtain the following:

V K

P

= ---

F_2

A_2

A_1

$= \text{------}F_1$

F_2

5 in.^2

0.5 in.^2

$= \text{------------------}(100 \text{ lbs}) = 1000 \text{ lbs}$

V_2

P_1

P_2

$= \text{------}V_1$

The relationship between temperature and pressure for a gas at constant volume
is expressed by Gay-Lussac's law. This law states that if the volume of
the vessel holding a gas is constant, then the pressure exerted by the gas on
the walls of the vessel will vary directly with the temperature in Kelvin (K) of
the gas.

Gay-Lussac's law can be expressed as follows:

$P = KT$ (5-10)

where K is a constant and the volume of the gas in the closed system is constant.
This relationship means that if the temperature in K is doubled, the
pressure exerted by the gas on the walls of the container will double. This concept
can be expressed mathematically as follows:

(5-11)

where P_1 and T_1 are the initial pressure and temperature of the gas, respectively,
and P_2 and T_2 are the final pressure and temperature in a fixed volume.

Example 5-3 illustrates a typical application of Gay-Lussac's law**.**

EXAMPLE 5-2

Problem: A gas sample occupies a volume of 3 ft^3 at a pressure of 4 psi and a
temperature of 60°F. What will be its volume if the pressure increases to 8 psi
and the temperature remains at 60°F?

Solution: Using Equation 5-9, we obtain the following:

V_2

P_1

P_2

$= \text{------}V_1$

V_2

4 psi

8 psi

$\text{------------} \; 3 \text{ ft} \times 3 \; 1.5 \text{ ft}^3 = =$

P_1

T_1

P_2

T_2

= ------

Gauge and Absolute Pressure

Absolute pressure is the pressure measured above total vacuum or zero absolute, where zero absolute represents a total lack of pressure. Gauge pressure is the pressure measured above atmospheric or barometric pressure. It represents the positive difference between measured pressure and existing atmospheric pressure.

Most pressure gauges and other pressure-measuring devices indicate a zero reading when the measuring point is exposed to the atmosphere. This point is called *zero psi*. In fact, most pressure instruments actually measure a difference in pressure. However, some instruments are designed to produce a reading that is referenced to absolute zero and to indicate a reading near 14.7 psi at sea level when the pressure point is exposed to atmospheric pressure. This reading is generally termed *psi*. Figure 5-5 illustrates the relationship between absolute and gauge pressure.

The equation for converting from gauge pressure (P_g) in psi to absolute pressure (P_a) in psi is given by the following:

$P_a = P_g + P_{atm}$ (when $P_g > P_{atm}$) (5-12)

$P_a = P_g - P_{atm}$ (when $P_g < P_{atm}$) (5-13)

EXAMPLE 5-3

Problem: A sample of gas occupies a fixed volume of 10 ft^3 at a pressure of 4 psi and a temperature of 25°C. What will its pressure be if the temperature of the gas is increased to 50°C?

Solution: From Gay-Lussac's law we know that $P_1/T_1 = P_2/T_2$ if temperature is in Kelvin. Thus, we must first convert the Celsius temperatures into Kelvin:

T_1 (K) = 25° + 273.14° = 298.14° and T_2 (K) = 50° + 273.14° = 323.14°.

Then, using Equation 5-11 and solving for P_2, we obtain

$$\frac{P_2}{T_2} = \frac{P_1}{T_1}$$

$$P_2 = \frac{(4\ \text{psi})\ 323.14}{298.14} = 4.33\ \text{psi}$$

where P_{atm} is atmospheric pressure.

It should be noted that a change in atmospheric pressure will cause a change in gauge pressure. Therefore, a change in barometric pressure will cause a change in the reading of a gauge-pressure-measuring instrument.

This principle can be best illustrated by Examples 5-4 and 5-5.

Manometers

The manometer is one of the first pressure-measuring instruments ever designed. Today, it is mainly used in the laboratory or to calibrate pressure instruments in the process industries. A manometer consists of one or two transparent tubes and two liquid surfaces. Pressure applied to the surface of

Figure 5-5. Relationship between absolute and gauge pressure

EXAMPLE 5-4

Problem: If a pressure instrument has a reading of 30 psi, find the absolute pressure if the local barometric reading is 14.6 psi.

Solution: Since $P_g > P_{atm}$, use Equation 5-12 to find the absolute pressure:

$P_a = P_g + P_{atm}$

P_a = 30 psi + 14.6 psi
P_a = 44.6 psi
0 Total Vacuum
Atm.
Pressure
Absolute Gauge
Atmospheric
Barometric Range
Chapter 5 – Pressure Measurement 137
one tube causes an elevation of the liquid surface in the other tube. The amount of elevation is read from a scale that is usually calibrated to read directly in pressure units.

In general, the manometer works as follows: An unknown pressure is applied to one tube, and a reference (known) pressure is applied to the other tube. The difference between the known pressure and the unknown pressure is balanced by the weight per unit area of the displaced manometer liquid. Mercury and water are two commonly used liquids in manometers; however, any fluid can be used. In fact, some manometers now use a fill liquid that has a specific gravity of 2.95 to avoid the environmental problems associated with mercury. The formula for the pressure reading of a manometer is given by the following:

$P = K_m (SG)h$ (5-14)

where

P = pressure in psi
h = the inches of displaced liquid
SG = the specific gravity of the manometer liquid
K_m = 0.03606 psi/in

The *specific gravity* of a material is the ratio of its density to that of water. It is therefore a pure number with no dimensions. *Specific gravity* is a very poor term since it has nothing to do with gravity. Relative density would describe

EXAMPLE 5-5
Problem: Find the absolute pressure if a vacuum gauge reads 11.5 psi and the atmospheric pressure is 14.6 psi.
Solution: When dealing with pressure below atmospheric pressure, you must use Equation 5-13:
$P_a = P_g – P_{atm}$
P_a = 11.5 psi – 14.6 psi
P_a = – 3.1 psi

138 Measurement and Control Basics, Fifth Ed.
the concept more precisely. But, the term *specific gravity* (SG) is widely used in engineering to reduce the number of dimensions in equations.

Example 5-6 shows how to calculate the amount of displacement of liquid in a manometer that is connected to a process tank.

Manometers can provide a very accurate measurement of pressure and are often used as calibration standards for other pressure-measurement devices. The pressure-measurement range of most manometers is usually from a few

EXAMPLE 5-6
Problem: Find the displacement in inches of a liquid that has a specific gravity of 2.95 in the manometer shown in Figure 5-6, if the pressure of the gas in the process tank is 3 psi.
Solution: Using Equation 5-14, we obtain:

$P = (0.03606)(SG)h$
Therefore,
$h = P/((0.03606)(SG))$
$h = (3 \text{ psi})/(0.03606)(2.95) = 28.2 \text{ inches}$
EXAMPLE 5-7
Problem: Calculate the pressure detected by a mercury manometer if the mercury is displaced 10 inches and the specific gravity of the mercury in the manometer is 13.54.
Solution: Using Equation 5-14, we obtain:
$P = (0.03606)(SG)h$
$P = (0.03606)(13.54)(10 \text{ inches})$
$P = 4.9 \text{ psi}$

inches to about 30 inches. The range depends on the physical length and arrangement of the tubes and the specific gravity of the fill fluid.
The most common type of manometer is the *U-tube*. The open tube manometer shown in Figure 5-6, for example, is used to measure the pressure in a process tank. It consists of a U-shaped tube that contains a liquid. One end of the tube is open to the atmosphere, and the other end is connected to the system whose pressure we want to measure.

Pressure Gauges

Pressure gauges are used for local indication and are the most common type of pressure-measurement instrument used in process industries. Pressure gauges consist of a dial or indicator and a pressure element. A pressure element converts pressure into a mechanical motion.
Most mechanical pressure elements rely on the pressure that acts on a surface area inside the element to produce a force that causes a mechanical deflection. The common elements used are *Bourdon tubes diaphragms* and *bellows elements*.
Figure 5-7 shows one of the most common and least expensive pressure gauges used in the process industries. This pressure gauge uses a "C" type Bourdon tube. In this device, a section of tubing that is closed at one end is
Figure 5-6. U-Tube manometer used on a process tank
y_1
y_2
$h = y_2 - y_1$
$P_1 = P$
$P_2 = P_{atm}$
Process Tank

partially flattened and coiled, as shown in Figure 5-7. When a pressure is applied to the open end, the tube uncoils. This movement provides a displacement that is proportional to the applied pressure. The tube is mechanically linked to a pointer on a pressure dial to give a calibrated reading.
A diaphragm is another device that is commonly used to convert pressure into a physical movement. A diaphragm is a flexible membrane. When two are fastened together they form a container called a *capsule*. In pressuremeasuring instruments, the diaphragms are normally metallic. Pressure applied inside the diaphragm capsule causes it to expand and produce motion along its axis. A diaphragm acts like a spring and will extend or contract until a force is developed that balances the pressure difference force. The amount of

movement depends on how much spring there is in the type of metal used. A wide variety of materials are used, including brass, phosphor bronze, beryllium-copper, stainless steel, Ni-Span-C, Monel, Hastelloy, titanium, and tantalum.

To amplify the motion that a diaphragm capsule produces, several capsules are connected end-to-end, as shown on Figure 5-8. You can use diaphragmtype pressure gauges to measure gauge, absolute, or differential pressure.

Figure 5-7. Bourdon tube pressure gauge

30
40 50 60
70
Pressure
"C" Bourdon
Tube

They are normally used to measure low pressures of 1 inch of Hg, but they can also be manufactured to measure higher pressures in the range of 0 to 330 psi. They can also be built for use in vacuum service.

The bellows pressure element is very similar to a diaphragm-type gauge in that it converts a pressure into a physical displacement. The difference is that typically the movement in a bellows is much more of a straight-line expansion.

A typical bellows-type pressure gauge is manufactured by forming many accordion-like pleats into a cylindrical tube, as shown in Figure 5-9. Bellows pressure cells are low-pressure cells of as little as 0 to 1 inch of Hg and as much as 0.5 to 30 psi. In vacuum service, they can be used to 30 inches of Hg. You can use the motion that the pressure input signal produces to position a pointer, recorder pen, or the wiper of a potentiometer.

Process Signal Transmitters

Sensors use various methods to measure process values, such as pressure, level, temperature and flow. The output of the sensors in most cases needs to be converted into a pneumatic, electrical, or digital signal that can be used in process control and measurement. The pneumatic transmitter generally converts the process value into a 3 to 15 psi signal that can be used for control or

Figure 5-8. Diaphragm-type pressure gauge

Pressure
Diaphragm
Capsules
Pressure
Indicator
0
30

indication. The electrical transmitter converts the measured process value into a 4 to 20 mA, direct current signal that is transmitted to process control systems. The digital transmitter converts the process measurement into a digital signal and it is the most sophisticated and powerful of the three transmitter types. It will be discussed next, followed by a discussion of electrical transmitters and then a typical pneumatic pressure transmitter.

Digital Transmitters

Digital transmitters can communicate with other control systems and instruments digitally. They are an intelligent instrument that is microprocessorbased with memory. They can be programmed to fit the measure application.
They are capable of reporting faults and performing calculations and generally have self-diagnostics capabilities. It is a common practice to call digital transmitters that use the Hart protocol "smart" instruments. Also, intelligent digital transmitters that communicate with some types of fieldbus are often called "fieldbus" transmitters. They can all be classified as "Digital Transmitters."
The calibration of an intelligent digital instrument can be changed remotely by pushing a few buttons on a hand-held calibrator connected anywhere to the signal wiring or by entering the information from a computer connected to the control system. This makes it unnecessary, for example, to go to the field with a stack of equipment, pump up a pressure, and carefully turn screws
Figure 5-9. Pressure bellows
Pressure
Bellows
Link to Indicator
Chapter 5 – Pressure Measurement 143
until the span of a dP cell is changed to a new value. Obtaining information from electrical or pneumatic transmitters was beyond the capability of past generation instrument and control systems, and the advantages of providing this capability has been part of the justification for many control system upgrades.
Many digital instruments can measure and report several variables. For example, a pressure transmitter may also report temperature. The "smart" instruments may be capable of reporting its specifications, such as model number, calibration, tag number, and other information. Many types of instrument failures can be detected by the transmitter itself and reported to a computerized maintenance management system, so a repair work order can be issued.
Another type of digital transmitter is the "wireless" sensor. The main advantage of wireless sensors is the elimination of signal and power wiring. The use of wireless networks in control systems has enabled measurement applications in sites that are difficult to access, or where the wiring costs cannot be justified. They are also cost effective in upgrading existing plants, for temporary installations, or for locations where a power source is not available.

Electrical Transmitters

The electrical transmitter uses just two wires to transmit the process measurement signal. The analog 4-20 mA DC signal can also power the field transmitter with its own supply voltage and can operate for long distances on a standard cable. Using the live zero (4 mA instead of 0 mA) it senses a cable break or instrument failure. It is not overly susceptible to electrical noise; it is highly accurate, and is low cost. One disadvantage is that the two wires can only carry one process variable.
As process control systems continue to evolve and the use of advanced communication systems improve, there is still a need for the simple analog 4-20mA signal. About twenty years ago, process industry experts stated that 4-20mA would disappear being replaced by digital networks or fieldbus solutions.

While it is true that communication systems have now taken a larger portion of the market share, 4-20mA transmitters are still used in significant numbers. The two main reasons for this are: first the highly-priced digital transmitters that are designed for specific networks are not always cost effective and second their intelligent features are not always needed in a control application.

The process control industry has also changed significantly, with more measurement and control systems being installed in smaller plant, like water treatment and food processing. It can still be stated that the 4-20mA signal is truly the last universal signal that is accepted by all the measurement and control users, vendors and professionals. Single control loops, smaller plants and transportable skid-type equipment will always have a need for these low-cost 4-20mA signal transmitters."

Pneumatic Pressure Transmitters

A typical pneumatic pressure transmitter is called a *force-balance pneumatic transmitter*. In this type of instrument, the pressure that is to be measured is applied to a metal diaphragm that is welded to the sides of a chamber. The force developed on the diaphragm is brought out of the chamber by a rigid rod called a *force bar*, which is attached to the diaphragm. A balanc-ing force developed by a pneumatic feedback bellows opposes this force. Imbalance between the capsule force and the feedback bellows force is sensed by a pneumatic nozzle-baffle. This simple pneumatic servo-mechanism is responsive to nozzle pressure and reestablishes the balance. As a result, pneumatic pressure is maintained so it is exactly proportional to applied pressure and is used as an output signal (usually 3 to 15 psi).

It should be noted that most pneumatic pressure transmitters actually measure a differential pressure (⊗P) that is applied to the high and low inputs of the transmitter. Pressure measurements are always made with respect to a reference point. Gauge pressure, for example, is referenced to atmospheric pressure. Absolute pressure measurement represents a pressure level above a complete vacuum, which is the absence of pressure or 0 psi. In either case, a measurement represents the difference in pressure between a value and the reference level. In a strict sense, all pressure measurements are differential pressure measurements.

Electrical Pressure Sensors

The electrical principles used to measure pressure displacement are numerous and varied. Most electrical pressure sensors employ capacitive, differential transformer, force balance, photoelectric, piezoelectric, potentiometric, resistive, strain gauge, or thermoelectric means of measurement. In many cases, the electronic or electrical device is used in conjunction with a mechanical device. For example, a piezoelectric crystal can be attached to a metal pres
sure-sensing diaphragm to produce an electrical signal that is proportional to pressure. We will discuss the various types in this section, but first we will address the characteristics of sensors.

Sensor Characteristics

Two important characteristics of sensors are sensitivity and accuracy. *Sensitivity* is a measure of the change in output of a sensor in response to a change in input. In general, high sensitivity is desirable in a sensor because a large change in output for a small change in input makes it easier to take a measurement. The value of sensitivity is generally indicated by the gain of the sensor. Thus, when a pressure sensor outputs 10 mV per psi, the sensitivity is 10 mV/psi.

In the case of an ideal sensor, the value of the output signal is only affected by the input signal. However, no practical sensor is ideal. In the case of a pressure sensor, variations in temperature, humidity, vibration, or other conditions can affect the output signal. The degree to which one of these factors affects the output is called the *sensitivity* of the sensor to that factor.

Temperature affects pressure sensors the most. The effect of temperature on the operation of a pressure sensor can be characterized by the following equation:

$S_o = aP + bT$ (5-15)

where

S_o = the sensor output

P = the pressure signal

T = the temperature

a and b = constants

A good pressure sensor should be very sensitive to pressure and not very sensitive to temperature changes. This balance is obtained if the value of the constant b is small and the value of a is large.

Accuracy is a term used to specify the maximum overall error to be expected from a device, such as one that measures a process variable. Accuracy usually is expressed as the degree of *inaccuracy* and takes several forms:

• Measured variable, as the accuracy is 1}پ psi in some pressure measurements. Thus, there is an uncertainty of 1}پ psi in any value of pressure measured.

• Percentage of the instrument full-scale (FS) reading. Thus, an accuracy of 0.5}پ% FS in a 10-volt full-scale voltage meter would mean the inaccuracy or uncertainty in any measurement is 0.05}پ volts.

• Percentage of instrument span, that is, percentage of the range of the instrument's measurement capability. Thus, for a device measuring 2}پ% of span for 20-50 psi range of pressure, the accuracy is (0.6}پ = (20-50)(0.02}پ psi.

• Percentage of the actual reading. Thus, for a 5}پ% of reading current meter, we would have an inaccuracy of 1.0}پ milliamps (ma) for a reading of 20 mA of current flow.

Example 5-8 demonstrates several common error calculations for a pressure instrument.

EXAMPLE 5-8

Problem: A pressure instrument has a span of 0-100 psi. A measurement results in a value of 60 psi for pressure. Calculate the error if the accuracy is (a) 0.5}پ% FS, (b) 1.00}پ% of span, and (c) 0.75}پ% of reading. What is the possible pressure in each case?

Solution: Using the definitions just given we find the following:
Error = (100)(0.005}پ psi) = 0.5}پ psi. So, the actual pressure reading is in the range of 59.5 to 60.5 psi.
Error = (100-0)(0.01}پ)psi = 1}پ psi. Thus, the actual pressure reading is in the range of 59 to 61 psi.
Error = (60)(0.0075}پ psi) = 0.45}پ psi. Thus, the pressure reading is in the range of 59.55 to 60.45 psi.

Chapter 5 – Pressure Measurement 147

Potentiometric-type Sensor

The potentiometric-type sensor is one of the oldest types of electric pressure transducers. It converts pressure into a variable resistance. A mechanical device such as a diaphragm is used to move the wiper arm of a potentiometer as the input pressure changes. A direct current voltage (dc V) is applied to the top of the potentiometer (pot), and the voltage that is dropped from the wiper arm to the bottom of the pot is sent to an electronic unit, as shown in Figure 5-10. The output of the electronic unit is normally a 4-to-20 maDC current. Potentiometric pressure instruments normally cover a range of 5 psi to 10,000 psi. They are rugged instruments and can be operated over a wide range of temperatures. The potentiometer's (pot) large moving mass and low friction result in low frequency response and make them susceptible to vibration. Resolution is determined by the potentiometer's element. Wire-wound resistive elements have poor resolution while plastic elements have infinite resolution. Moreover, potentiometers are subject to wear because of the mechanical contact between the slider and the resistance element. Therefore, with potentiometers the instrument life is fairly short, and they tend to become noisier as the pot wears out.

Figure 5-10. Potentiometric pressure sensor

Pressure
Diaphragm
Capsules
+V
Pot Electronics
Unit
+
_

148 Measurement and Control Basics, Fifth Ed.

Piezoelectric-type Sensor

A certain class of crystals, called piezoelectric, produce an electrical signal when they are mechanically deformed. The voltage level of the signal is proportional to the amount of deformation. Normally, the crystal is mechanically attached to a metal diaphragm. One side of the diaphragm is connected to the process fluid to sense pressure, and a mechanical linkage connects the diaphragm to the crystal.

The output voltage signal from the crystal is very small (normally in the microvolt range), so you must use a high-input impedance amplifier. The amplifier must be mounted within a few feet of the sensor to prevent signal loss. The crystals can tolerate temperatures up to 400°F, but they are affected by varying temperatures and must be temperature compensated.

Capacitance-type Sensor

Another example of an electronic unit connected to a pressure diaphragm is the variable capacitor pressure-sensing cell. A capacitor consists of two metal plates or conductors that are separated by an insulating material called a *dielectric*. In a capacitance-type pressure sensor, a differential pressure is applied to a diaphragm. This in turn causes a filling fluid to move between the isolating diaphragm and a sensing diaphragm. As a result, the sensing diaphragm moves toward one of the capacitor plates and away from the other, thus changing the capacitance of the device. Since capacitance is inversely proportional to the distance between the plates, a change in pressure applied to the cell will result in a change of capacitance. This change in capacitance can be used to measure pressure. A pair of electrical leads is connected to an electronic circuit that measures the change in capacitance. This capacitance change is then converted into an electronic signal in the transmitter, which is calibrated in pressure units.

There are two common electrical methods for detecting the capacitance change. In one method, the change is detected by measuring the magnitude of an AC voltage across the plates when they are excited. In the other method, the sensing capacitor forms part of an oscillator, and the electronic circuit changes the frequency to tune the oscillator. These changes in frequency are then electronically converted into a pressure change.

Variable Inductance Sensor

Figure 5-11 shows another example of an electrical sensor used with a pressure-sensing diaphragm. Inductance, a fundamental property of electromagnetic circuits, is the ability of a conductor to produce induced voltage when the current in the circuit varies. A long wire has more inductance than a short wire since more conductor length is cut by magnetic flux, producing more induced voltage. Similarly, a coil of wire has more inductance than the equivalent length of straight wire because the coil concentrates magnetic flux. The core material around which the coil is wound also affects the inductance.

In other words, the inductance of a coil of wire or inductor depends on the number of turns and the magnetic properties of the material around the wire. The variable inductance device shown in Figure 5-11 uses two coils magnetically coupled through a core. The core changes properties as the applied pressure moves the diaphragm. The inductance is measured using a variety of electronic circuits. For example, you may use the pressure-sensing variable inductor as a component in an oscillator circuit.

Strain Gauge Pressure Sensors

The deformation of a material is called *strain*, and the mechanical force that produces the deformation is called *stress*. Strain is a unitless quantity, but it is common practice to express it as the ratio of two length units, such as in./in. or m/m.

A strain gauge is a device that changes resistance when stretched. A typical unbounded strain gauge is shown in Figure 5-12. It consists of multiple runs

Figure 5-11. Variable inductance pressure sensor

Sensing Coils
Diaphragm
P Magnetic Cores 1
P2

of very fine wire that are mounted to a stationary frame on one end and a movable armature on the other. The movable armature is generally connected to a pressure-sensing bellows or to a diaphragm. The multiple runs of wire amplify small movements along the direction of the wire. Very small pressure changes can be detected if there are a large number of wire runs.

In Chapter 3, we saw that the resistance of a metal wire is given by the following equation:

(5-16)

where

R_o = the original wire resistance (∧)

r = the resistivity of the wire in (∧-m)

l_o = the wire length (m)

A_o = the starting cross-sectional area (m2)

Suppose the wire is stretched. Then, we know that the wire will elongate by some amount ⊗l, so the new length is now $l = l_o +$ ⊗l. It is also true that under this stress/strain condition, though the wire lengthens, its volume will remain constant. Because the volume unstretched is $V = l_o A_o$, it follows that the crosssectional area must decrease by some area ⊗A, so the volume (V) does not change. The new area will be A_o - ⊗A. Therefore,

V = $l_o A_o = (l_o +$ ⊗$l)(A_o -$ ⊗$A)$ (5-17)

Figure 5-12. Unbonded strain gauge

Wire Elements

Movable

Armature

Stationary

Frame

R_o r

l_o

A_o

= ------

Now, because both the length and the area have changed, the resistance of the wire will also change to:

(5-18)

Using Equations 5-17 and 5-18, the new resistance is given approximately by the following:

(5-19)

From this equation, we can obtain the resistance change as:

(5-20)

Equation 5-20 is the basic equation that underlies the operation of wire strain gauges because it shows that the strain (⊗l/l_o) converts directly into a resistance change. Example 5-9 illustrates this concept.

Example 5-9 points out that in strain gauges the change in resistance is very small. This means that when using a strain gauge, sensitive electronic circuits must be used to obtain an accurate pressure measurement.

EXAMPLE 5-9

Problem: Find the change in wire resistance for a strain gauge that has a nominal wire resistance of 100∧, when it is subjected to a strain of

1000 μ m/m.
Solution: The change in strain gauge resistance can be found by using Equation 5-19:
⊗R = 2(100∧)(1000 x 10–6) = 0.2∧
R r
lo + ⊗l
Ao – ⊗A
= --------------------
R r
lo
Ao
------ 1 2⊗l
lo
⎝ + -----⎠
H ⎛ ⎞
⊗R 2R⊗l
lo
H -----
⊗R 2R⊗l
lo
H -----

It is important to note that the signal produced by most electronic pressuresensing elements cannot be sent more than a few feet. Therefore, most electronic pressure devices have a transmitter mounted on the sensor. The transmitter converts the measured signal into a 4-to-20-mA current signal, which is sent to a local indicator or to a central control area for indication, control, or recording.

Pressure Transmitter Applications

The most common application for a pressure transmitter is measuring liquid level in a process tank, as shown in Figure 5-13. Pressure transmitters determine level by using the principle that pressure is proportional to the height of the liquid multiplied by its specific gravity (SG). The pressure generated by the liquid is directly related to its height, and this pressure is independent of volume and the shape of the tank. Thus, 100 inches of water will produce 100 inH_2O of pressure since water has a specific gravity of one. If the specific gravity is different, the pressure changes proportionately. For example, if the specific gravity is 0.95, a liquid level of 100 inches produces a pressure of 95 inH_2O. If the specific gravity is 1.1, then a level of 100 inches produces 110 inH_2O of pressure.
Both gauge and differential pressure (dP) transmitters can be used to measure level. Gauge pressure transmitters are simply dP transmitters or cells that have their low-pressure port connected to the atmosphere. Either type of
Figure 5-13. Open tank, dP cell horizontal to tap
Top Instrument Tap
dP Transmitter
4 to 20 mA DC
Atm.
Atm.
L_{max} = 100”

L_{min} = 0"
Liquid, SG = 0.95
Hi Lo

instrument is appropriate for use on an open tank or on a tank vented to the atmosphere, as shown in Figure 5-13. If the pressure inside a tank is either positive or negative, you must use a dP cell. In this case, you would connect the low-pressure port to the pressure above the fluid.
In the open-tank application shown in Figure 5-13, the pressure transmitter measures the pressure between the minimum fluid level (L_{min}) at the instrument tap and the maximum fluid level (L_{max}) in the tank using the high (Hi) pressure port on the pressure cell. The low (Lo) pressure side of the cell senses only the atmospheric pressure. Since atmospheric pressure is sensed by both sides of the dP cell, its effect is cancelled.
The transmitter output is a 4-to-20-milliamp (mA) current signal that represents the fluid level in the tank. The span points for the dP cell are calculated as follows:
4 mA = L_{min} x SG
= 0 inches x 0.95
= 0 inH_2O
20 mA = L_{max} x SG
= 100 inches x 0.95
= 95.0 inH_2O
So the span of the transmitter is given by the following:
Span = (L_{max} – L_{min}) x SG
= (95.0 – 0) inH_2O
= 95.0 inH_2O
The 4-to-20-maDC current output signal from the dP transmitter is calibrated from 0 to 95 inH_2O.
In the next application, shown in Figure 5-14, the pressure transmitter is mounted 20 inches below the bottom instrument tap on the process tank. To calculate the 4 mA point for the transmitter, we need to consider the pressure that is developed by the process fluid in the extra 20 inches of distance, d. In this case, the span points for the dP cell are calculated as follows:

4 mA = (L_{min} + d) x SG
= (0 + 20) inches x 0.95
= 19 inH_2O
20 mA = (L_{max} + d) x SG
= (100+ 20) x SG
= 120 inches x 0.95
= 114 inH_2O
So, the dP transmitter must be calibrated from 19 inH_2O to 114 inH_2O.
In the next application, shown in Figure 5-15, the tank is closed, and there is a "dry leg" between the instrument connection near the top of the tank and the low (Lo) pressure port on the dP cell. A "dry leg" is defined as the length of instrument piping between the process and a pressure transmitter that is filled with air or another noncondensing gas.

In the application shown in Figure 5-15, the high-pressure (HP) port senses the liquid level and the pressure above it. The low-pressure (LP) port senses

Figure 5-14. Open tank – dP cell below bottom tap

Top Instrument Tap
dP Cell
Atm.
L_{max} = 100”
L_{min} = 0”
Hi Lo
D = 20”
Liquid, SG = 0.95
Bottom Instrument Tap
4 to 20 mA DC

only the pressure above the liquid. The impact of the static pressure in the closed tank is eliminated by using the differential pressure transmitter. The dP transmitter output is a 4-to-20-milliamp (mA) current signal that represents the fluid level in the tank.

The span points for the dP cell are calculated as follows:

4 mA = L_{min} x SG
= 0 inches x 0.95
= 0 inH_2
O
20 mA = L_{max} x SG
= 100 inches x 0.95
= 95.0 inH_2
O

So, the differential pressure transmitter is calibrated for 0 to 95.0 inH_2O.

In the next application, shown in Figure 5-16, the tank is closed, and there is a “wet leg” between the top instrument tap and the low-pressure (LP) side of the dP cell. A “wet leg” is defined as the length of instrument piping between the process and a pressure transmitter that is filled with a compatible fluid and kept at a constant height.

Figure 5-15. Closed tank with dry leg and horizontal dP transmitter

L_{max} = 100”
L_{min} = 0”
Liquid, SG = 0.95
Hi Lo
Static Pressure
h = 120”
dP Transmitter 4 to 20 mA DC

Since the reference leg is wet or filled, you must make a correction for the weight of the fluid in the wet leg. The specific gravity of the wet leg is 1.2 for the application shown in Figure 5-16. The fluid in the wet leg should be heavier than the process liquid. It is also important to maintain a constant height for the fill fluid in the wet leg.

The span points for the dP cell are calculated as follows:

4 mA = (L_{min} x SG) – (h x SG_w)
= (0″ x 0.95) – (120″ x 1.2)
= –144 inH_2O
20 mA = (L_{max} x SG) – (h x SG_w)
= (100 inches x 0.95) – (120″ x 1.2)

= (95.0 – 144) inH2O
= –49 inH2O
So, the calibrated span for the dP transmitter is –144 to – 49 inH2O.
The final pressure transmitter application we will discuss is shown in Figure 5-17. It is a closed tank that has a wet leg and a dP transmitter below the bot-
Figure 5-16. Closed tank with wet leg and microprocessor-based dP cell
L_{max} = 100”
L_{min} = 0”
Liquid, SG = 0.95
Hi Lo
Static Pressure
Wet Leg, SG_w = 1.2
h = 120”
Microprocessor - based dP Cell Digital Signal

tom instrument tap. The dP cell is used to compensate for the static pressure in the process tank.
Since the reference leg is wet or filled, we must make a correction for the weight of the fluid in the wet leg. We also need to correct for the fact that the dP cell is mounted 20 inches below the bottom instrument tap.
The span calibration points for the differential pressure instrument in Figure 5-17 are calculated as follows:
4 mA = $(L_{min} + d) \times SG - (h + d) \times SG_w$
= (0″ + 20″) x 0.95 – (120″ + 20″) x 1.2
= 19″ – 168″
= –149 inH2O
20 mA = $(L_{max} + d) \times SG - (h + d) \times SG_w$
= (100″ + 20″) x 0.95 – (120″+ 20″) x 1.2
= 114″ – 168″
= –54 inH2O
Figure 5-17. Closed tank with wet leg and “smart” dP cell below bottom tap
“Smart” dP Cell
L_{max} = 100”
L_{min} = 0”
Hi Lo
Digital Signal
d = 20”
Liquid, SG = 0.95
Wet Leg, SG_w = 1.2
d = 120”
Static Pressure

So, the calibrated span of the dP transmitter is –149 to –54 inH2O.
In standard mount or dry leg applications, the accuracy of the level measurement is directly related to the accuracy of the pressure transmitter. However, the dry leg must be dry; any condensation in the leg will create an error in the level measurement. Condensation in most cases is prevented by doing heat tracing of the reference leg. However, if condensation is a significant problem, it may be better to use a wet leg installation.
With a wet leg installation, any change in the height or density of the wet leg fluid influences the accuracy of the level measurement. It is important to maintain the height of the wet leg fluid constant. If the height of the wet leg changes, it will result in a reference point shift. A large change in ambient

temperature will cause a change in the density of the fill fluid. This in turn will change both the zero and maximum calibration points on the transmitter. If both the height and density of the fill fluid change, the measurement problems are compounded.

EXERCISES

5.1 Find force F_2, given the following data on the hydraulic press shown in Figure 5-4: A_1=1.0 in.^{2}, A_2=10 in.^{2}, and F_1=25 lbs.

5.2 A gas sample occupies a volume of 5 ft^3 at a pressure of 20 psi and a temperature of 70°F. What will be its volume if the pressure increases to 30 psi and the temperature remains at 70°F?

5.3 A sample of gas occupies a fixed volume at a pressure of 15 psi and a temperature of 30°C. Find the pressure of the gas if the temperature of the gas is increased to 40°C.

5.4 Find the gauge pressure if the absolute pressure reading is 50 psi and the local barometric pressure is 14.5 psi.

5.5 Find the absolute pressure if the reading of a pressure gauge is 21 psi and the local barometric pressure is 14.3 psi.

5.6 Find the displacement in inches for a mercury manometer with a specific gravity of 13.54, if the pressure applied is 1 psi.

5.7 Calculate the pressure detected by a U-tube manometer if the liquid in the manometer has a specific gravity of 2.95, and it is displaced 20 inches when pressure is applied.

5.8 Calculate the pressure detected by a mercury manometer if the mercury is displaced 4 inches. The specific gravity of the mercury in the manometer is 13.54.

5.9 List the sensing elements commonly used in pressure gauges.

5.10 List the two methods used in capacitance-type pressure sensors to detect the capacitance change produced by a pressure change.

5.11 A pressure instrument has a span of 0-100 inH_2O. A measurement results in a value of 50 inH_2O for pressure. Calculate the error if the accuracy is (a) 2.0}پ% FS, (b) 1.0}پ% of span, and (c) 0.5}پ% of reading. What is the possible pressure in each case?

5.12 Find the change in wire resistance for a strain gauge that has a nominal wire resistance of 150 ∧ when it is subjected to a strain of 800 μm/m.

5.13 Calculate the span of a differential pressure transmitter that is mounted 10 inches below the bottom instrument tap on an open process tank that contains a liquid with a specific gravity of 1.1. Assume that the minimum level in the process tank is 0 inches, and the maximum level is 50 inches.

٦- الاسئلة البعدية

Find the change in wire resistance for a strain gauge that has a nominal wire resistance of 150 ∧ when it is subjected to a strain of 800 μm/m.

رقم المحاضرة:	١٤
عنوان المحاضرة:	Temperature Measurement, Rotating methods
اسـم المدرس:	كازيوه فريق صديق
الفئة المستهدفة :	طلبة المعهد التقني /قسم تقنيات الصناعات الكيمياوية
الهدف العام من المحاضرة :	تعليم الطالب لطرق قياس درجة الحرارة
الأهداف السلوكية او مخرجات التعلم:	١-معرفة درجة حرارة الأجهزة ٢- السيطرة على درجة حرارة الاجهزة
استراتيجيات التيسير المستخدمة	١- التعلم التفاعلي: تشجيع النقاشات والأسئلة لتحفيز التفكير. ٢- العروض العملية: تقديم تجارب حية أو عروض توضيحية للمفاهيم. ٣- التقييم المستمر: تقديم اختبارات قصيرة أو أنشطة تقييمية خلال الدروس. ٤- التغذية الراجعة الفورية: إعطاء ملاحظات مباشرة للطلاب لتحسين الأداء. ٥- التطبيق العملي: تنفيذ مشاريع أو تمارين عملية لمحاكاة الواقع.
المهارات المكتسبة	حفاظ على سلامة الأجهزة من عوامل درجة الحرارة
طرق القياس المعتمدة	

٤ - الاسئلة القبلية

How much will a 10 m-long copper rod expand when the temperature is changed from 0 to 100°C?

٥- المحتوى العلمي

محتويات الفصل

Temperature Measurement

Introduction

This chapter explores the more common temperature-measuring techniques and transducers used in process control, including filled-system thermometers, bimetallic thermometers, thermocouples, resistance temperature detectors (RTDs), thermistors, and integrated-circuit (IC) temperature sensors. We will discuss each transducer type in detail, but we will first consider the history of temperature measurement, temperature scales, and reference temperatures. Temperature is a measure of the internal molecular activity of a material. As the level of molecular activity increases, the temperature of the material increases. Hot and cold are subjective descriptions of a change in molecular activity.

History of Temperature Measurement

The first known temperature-measuring device was invented by Galileo in about 1592. It consisted of an open container filled with colored alcohol and a long, narrow-throated glass tube with a hollow sphere at the upper end, which was suspended in the alcohol. When it was heated, the air in the sphere expanded and bubbled through the liquid. Cooling the sphere caused the liquid to move up the tube. Changes in the temperature of the sphere and the surrounding area could then be observed by the position of the liquid inside the tube. This "upside-down" thermometer was a poor indicator, however, since the level changed with atmospheric pressure, and the tube had no scale.

Temperature measurement gained in accuracy with the development of the Florentine thermometer, which had a sealed construction and a graduated scale.

In the years to come, many thermometric scales were designed, all of which were based on two or more fixed points. However, no scale was universally recognized until the early 1700s, when Gabriel Fahrenheit, a German instrument maker, designed, and made, accurate and repeatable mercury thermometers. For the fixed point on the low end of his temperature scale, Fahrenheit used a mixture of ice water and salt. This was the lowest temperature he could reproduce, and he labeled it "zero degrees." The high end of his scale was more imaginative; he chose the body temperature of a healthy person and called it 96 degrees.

The upper temperature of 96 degrees was selected instead of 100 degrees because at the time it was the custom to divide things into twelve parts. Fahrenheit, apparently to achieve greater resolution, divided the scale into twentyfour, then forty-eight, and eventually ninety-six parts. It was later decided to use the symbol °F for degrees of temperature in the Fahrenheit scale, in honor of the inventor. The Fahrenheit scale gained popularity primarily because of the repeatability and quality of the thermometers that Fahrenheit built.

Around 1742, Swedish astronomer Anders Celsius proposed that the melting point of ice and the boiling point of water be used for the two fixed temperature points. Celsius selected zero degrees for the boiling point of water and 100 degrees for the melting point of water. Later, the end points were reversed, and the centigrade scale was born. In 1948, the name was officially changed to the Celsius scale and the symbol °C was chosen to represent "degrees Celsius or centigrade" of temperature.

Temperature Scales

It has been experimentally determined that the lowest possible temperature is –273.15°C. The Kelvin temperature scale was chosen so that its zero is at –273.15°C, and the size of one Kelvin unit was the same as the Celsius degree. Kelvin temperature is given by the following formula:

$T = T(°C) + 273.15$ (7-1)

Another scale, the Rankine scale (°R) is defined in the same way—with –273.15°C as its zero—and is simply the Fahrenheit equivalent of the Kelvin scale. It was named after an early pioneer in the field of thermodynamics, W. J. M. Rankine. The conversion equations for the other three modern temperature scales are as follows:

(7-2)

$T(°R) = T(°F) + 459.67$ (7-3)

(7-4)

You can use these equations to convert from one temperature scale to another, as illustrated in Examples 7-1 and 7-2.

EXAMPLE 7-1

Problem: Express a temperature of 125°C in (a) degrees °F and (b) Kelvin.

Solution: (a) Convert to degrees Fahrenheit as follows:

T (°F) = (225 + 32) °F

T = 257°F

(b) Convert to Kelvin as follows:

T (K) = *T*(°C) + 273.15

T (*K*)= 125°C + 273.15

T = 398.15 *K*

T °C ( ) 59

= --(*T*(°F) – 32°)

T °F ( ) 95

= --*T*(°C) + 32°

T(°F) 9

5

= --*T*(°C) + 32°

T(°F) 9

5

= --(125°C) + 32°

Reference Temperatures

We cannot build a temperature divider the way we can a voltage divider, nor can we add temperatures as we would add lengths to measure distance. Instead, we must rely on temperatures established by physical phenomena that are easily observed and consistent in nature.

The International Temperature Scale (ITS) is based on such phenomena. Revised in 1990, it establishes the seventeen reference temperatures shown in Table 7-1. The ITS-90, as this new version is called, is designed so that temperature values obtained on it do not deviate from the Kelvin thermodynamic temperature values by more than the uncertainties of the Kelvin values as they existed at the time the ITS-90 was adopted. Thermodynamic temperature is indicated by the symbol *T* and has the unit known as the Kelvin, symbol *K*. The size of the Kelvin is defined to be 1/273.16 of the triple point of water. A triple point is the equilibrium temperature at which the solid, liquid, and vapor phases coexist.

Since these fixed temperatures are our only reference, we must use instruments to interpolate between them. However, achieving accurate interpola-

EXAMPLE 7-2

Problem: Express a temperature of 200°F in degrees Celsius and then degrees Kelvin.

Solution: First, we convert 200°F to degrees Celsius as follows:

T = 93.33°C

Now, we convert the temperature in degrees Celsius to Kelvin as follows:

T (K) = *T*(°C) + 273.15

T (*K*)= 93.33°C + 273.15

$T = 366.48\ K$

T °C ( ) 59

= --(T(°F) – 32°)

T 59

= --(200 – 32)°C

tion can require the use of some fairly exotic transducers, many of which are too complicated or expensive to use in process control applications.

Filled-System Thermometers

Many physical properties change with temperature, such as the volume of a liquid, the length of a metal rod, the electrical resistance of a wire, the pressure of a gas kept at constant volume, and the volume of a gas kept at constant pressure. Filled-system thermometers use the phenomenon of thermal expansion of matter to measure temperature change.

The filled thermal device consists of a primary element that takes the form of a reservoir or bulb, a flexible capillary tube, and a hollow Bourdon tube that actuates a signal-transmitting device and/or a local indicating temperature dial. A typical filled-system thermometer is shown in Figure 7-1. In this system, the filling fluid, either liquid or gas, expands as temperature increases.

Table 7-1. Defining Fixed Points of the ITS-90

DESCRIPTION	K	°C
Vapor pressure (VP) point of helium	3 to 5	-270.15 to -268.15
Equilibrium hydrogen at triple point (TP)	13.8033	259.3467
Equilibrium hydrogen at VP point	H17	H-256.15
Equilibrium hydrogen at VP point	H 20.3	H-252.85
Neon at TP	24.5561	248.5939
Oxygen at TP	54.3584	218.7916
Argon at TP	83.8058	189.3442
Mercury at TP	234.3156	38.8344
Water at TP	273.16	0.01
Gallium at melting point (MP)	302.9146	29.7646
Indium at freezing point (FP)	429.7485	156.5985
Tin at FP	505.078	231.928
Zinc at FP	692.677	419.527
Aluminum at FP	933.473	660.323
Silver at FP	1234.93	961.78
Gold at FP	1337.33	1064.18
Copper at FP	1357.77	1084.62

This causes the Bourdon tube to uncoil and indicate the temperature on a calibrated dial.

The filling or transmitting medium is a vapor, a gas, mercury, or another liquid. The liquid-filled system is the most common because it requires a bulb with the smallest volume or permits a smaller instrument to be used.

The gas-filled system uses the perfect gas law, which states the following for an ideal gas:

$T = kPV$ (7-5)

where

T = temperature

k = constant

P = pressure

V = volume

If the volume of gas in the measuring instrument is kept constant, then the ratio of the gas pressure and temperature is constant, so that:

(7-6)

Figure 7-1. Filled bulb thermometer

Volatile Liquid

Filled Bulb

Vapor Filled

P_1

T_1

P_2

T_2

= ------

The only restrictions on Equation 7-6 are that the temperature must be expressed in degrees Kelvin and the pressure must be in absolute units. Example 7-3 shows how to calculate the temperature for a change in pressure of a fixed volume temperature detector.

Bimetallic Thermometers

A bimetallic strip curves or twists when exposed to a temperature change, as Figure 7-2 shows, because of the different thermal expansion coefficients of the metals used in it. Bimetallic temperature sensors are based on the principle that different metals experience thermal expansion with changes in temperature. To understand thermal expansion, consider a simple model of a solid, the atoms of which are held together in a regular array of forces that have an electrical origin. The forces between atoms can be compared to the forces that would be exerted by an array of springs connecting the atoms together. At any temperature above absolute zero (–273.15°C), the atoms of the solid vibrate. When the temperature is increased, the amplitude of the

EXAMPLE 7-3

Problem: A gas in a fixed volume has a pressure of 30 psi at a temperature of 20°C. What is the temperature in °C if the pressure in the detector has increased to 35 psi?

Solution: First, convert the temperature of 20°C to the absolute scale of Kelvin using Equation 7-1:

$T = T\,(°C) + 273.15$

$T = 20 + 273.15 = 293.15°$

Now, use Equation 7-6 to find the new temperature that the detector is measuring:

Finally, convert this value for T_2 to °C:

$T_2 = (342° – 273.15°) = 68.85°C$

T_1

P_2

P_1

------T_1

35 psi

30 psi

(----------------)

= = ( ) 293.15° = 342°

vibrations increases, and the average distance between atoms increases. This leads to an expansion of the whole body as the temperature is increased. The change in length that arises from a change in temperature (⊗*T)* is designated by ⊗*L*. Through experimentation, we find that the change in length ⊗*L* is proportional to the change in temperature ⊗*T* and the original length *L*. Thus,

⊗*L*= *kL*⊗*T* (7-7)

where *k* is called the *coefficient of linear expansion*. This coefficient has different values for different materials. Table 7-2 lists the experimentally determined values for the average coefficient of linear expansion of several common solids in the temperature range of 0 to 100°C.

Example 7-4 illustrates how to calculate the expansion of a metal rod with a temperature increase.

Figure 7-3 shows a typical bimetallic dial thermometer using a spiral wound element. The spiral element provides a larger bimetallic element in a smaller

Figure 7-2. Bimetallic strip

Table 7-2. Thermal Expansion Coefficient

MATERIAL	EXPANSION COEFFICIENT (*K*)
Aluminum	25 x 10–6°C
Copper	16.6 x 10–6°C
Steel	6.7 x 10–6°C
Beryllium/copper	9.3 x 10–6°C

Fixed End Free End Low Expansion
coefficient
k_2
k_1
High Expansion
$k_2 < k_1$ coefficient
T_o
$T < T_o$

area, and it can measure smaller changes in temperature. It is a low-cost instrument but has the disadvantages of relative inaccuracy and a relatively slow response time. It is normally used in temperature measurement applications that do not require high accuracy.

Thermocouples

Thermoelectric Circuit

When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, a continuous current flows in the “thermoelectric” circuit. Thomas Seebeck made this discovery in 1821. This thermoelectric circuit is shown in Figure 7-4a. If this circuit is broken at the center, as shown in Figure 7-4b, the new open-circuit voltage (known as “the Seebeck voltage”) is a function of the junction temperature and the compositions of the two metals.

EXAMPLE 7-4

Problem: How much will a 4 m-long copper rod expand when the temperature is changed from 0 to 100°C?

Solution: First, find the length of the rod at 0°C and at 100°C, then find the change in length. Using Equation 7-7 at 0°C,

⊗*L* = *kL*⊗*T*

or

$L_o = kL(T_o - T_{20}) + L$

$L_o = (16.6 \times 10^{-6}/°C)\ 4\ m\ (0 - 20)°C + 4\ m$

$L_o = 3.9987 m$

At 100°C we have the following:

$L_{100} = (16.6 \times 10^{-6}/°C)\ 4\ m(100 - 20)°C + 4\ m$

$L_{100} = 4.00531\ m$

Thus, the expansion in the rod is $L_{100} - L_o = 0.00661$ m

198 Measurement and Control Basics, Fifth Ed.

Figure 7-3. Bimetallic dial thermometer

Figure 7-4. The thermoelectric circuit

Fixed End
Free End
Spiral Wound
Element
Fixed End
Free End Attached
to Pointer Shaft
Rotating Shaft
0
10
20
30
40 50
100
90
80
70
60
Current Flow
Metal 1
Metal 2
a) The Seebeck Effect
Heat
Connection
+
_
V_{ab}
b) The Seebeck Voltage (V_{ab})
Metal 1
Metal 2
Heat

Chapter 7 – Temperature Measurement 199

All dissimilar metals exhibit this effect, and this configuration of two dissimilar metals joined together is called a *thermocouple*, which is abbreviated TC.

The most common TCs and their normal temperature ranges are listed in Table 7-3.

For small changes in temperature, the Seebeck voltage is linearly proportional to temperature:

$V_{ab} = \langle(T_1 - T_2)$ (7-8)

where 〈, the Seebeck coefficient, is the constant of proportionality.

Example 7-5 shows how to calculate the Seebeck voltage for a thermocouple.

Table 7-3. Standard Thermocouple Types and Ranges

TYPE	MATERIAL	**NORMAL RANGE, C**
J	Iron-constantan	–190 to 760°C
T	Copper-constantan	–200 to 37°C
K	Chromel-alumel	–190 to 1260°C
E	Chromel-constantan	–100 to 1260°C

S 90% platinum + 10% rhodium-platinum 0 to 1482°C
R 87% platinum + 13% rhodium-platinum 0 to 1482°C

EXAMPLE 7-5

Problem: Find the Seebeck voltage for a thermocouple with 〈= 40 ⌠v/°C if the junction temperatures are 40°C and 80°C.

Solution: Using Equation 7-8, the Seebeck voltage can be found as follows:

V_{ab} = 〈 ($T_1 - T_2$)

V_{ab} = 40 ⌠v/°C (80°C – 40°C) = 1.6 mv

Thermocouple Tables

To take advantage of the voltage that thermocouples produce, scientists have developed comprehensive tables of voltage versus temperature for many types of thermocouples. These tables (presented in Appendix B) give the voltage that results for a particular type of thermocouple when the reference junctions are at 0°C and the measurement junction is at a given temperature. For example, according to Table B-4 in Appendix B, for a type K thermocouple at 200°C with a 0°C reference, the voltage produced is as follows:

V(200°C) = 8.13 mV (type K, 0°C)

Conversely, if a voltage of 29.14 mV is measured with a type K thermocouple with a 0°C reference, we find from Table B-4 that:

T(29.14 mV) = 700°C (type K, 0°C)

However, in most cases the TC voltage does not fall exactly on a table value. When this happens, you must interpolate between the table values that bracket the desired value. You can find an approximate value of temperature by using the following interpolation equation:

(7-9)

In this equation, the measured voltage V_m lays between a higher voltage V_h and lower voltage V_l given in the tables. The temperatures that correspond to these voltages are T_h and T_l. Example 7-6 illustrates this concept.

Measuring Thermocouple Voltage

You cannot measure the Seebeck voltage directly because you must first connect a voltmeter to the thermocouple, and the voltmeter leads create a new thermoelectric circuit.

Consider a digital voltmeter (DVM) that is connected across a copper-constantan (type T) thermocouple. The voltage output is shown in Figure 7-5. We would like the voltmeter to read only V_1, but to measure the output of junction J1 we have connected the voltmeter, which created two more metallic junctions: J2 and J3. Since J3 is a copper-to-copper junction, it creates no thermal voltage ($V_2 = 0$). However, J2 is a copper-to-constantan junction, which will add a voltage V_2 in opposition to V_1. The resultant voltmeter reading *V* will be proportional to the temperature difference between J1 and J2. This

T_m T_l

$(T_h - T_l)$

$(V_h - V_l)$

= ----------------------$(V_m - V_l)$

indicates that we cannot find the temperature at J1 unless we first find the temperature of J2.

One way to determine the temperature of J2 is to physically put the junction into an ice bath. This forces its temperature to be 0°C and establishes J2 as the
EXAMPLE 7-6
Problem: A voltage of 6.22 mV is measured with a type J thermocouple at a 0°C reference. Find the temperature of the measurement junction.
Solution: From Table B-1 in Appendix B we see that V_m = 6.22 mv lies between V_l = 6.08 mv and V_h = 6.36 mv, with corresponding temperatures of T_l = 115°C and T_h = 120°C, respectively. Therefore, using Equation 7-10, we can find the junction temperature as follows:
T_m = 117.5°C
Figure 7-5. Measuring thermocouple voltage with DVM
T_m 115°C (120°C – 115°C)
(6.36mV – 6.08mV)
= + ---(6.22mV – 6.08mV)
+
_
Cu J3
J2
J1
Copper (Cu)
Cu Constantan (C)
+
_
V
Digital Voltmeter (DVM)
J3
Cu Cu
J2
Cu V C 2
DVM
V J1
V_3= 0
DVM
202 Measurement and Control Basics, Fifth Ed.
"reference junction," as shown in Figure 7-6. Since both voltmeter terminal junctions are now copper-copper, they create no thermal voltage, and the reading "V" on the voltmeter is proportional to the temperature difference between J1 and J2.
Now the voltmeter reading is as follows:
$V = V_1 – V_2 = \langle\ (T_{J1} + T_{J2})$
If we specify T_{J1} in degrees Celsius,
T_{J1} (°C) + 273.15 = T_{J1}(K)
then V becomes the following:
$V = V_1 - V_2$
$V = \langle\ (T_{J1} + 273.15) - (T_{J2} + 273.15)$
$V = \langle\ (T_1 - T_2)$
Figure 7-6. External reference junction
Cu J3
J4
J1
Cu
+
_
V

DVM
V_1
Cu
Cu V_2 C
a) Ice Bath Circuit Ice Bath, T = 0°C
+
J1
T = 0°C
J2
V_2=0 C
Cu
Cu
V
b) Equivalent Circuit
J2
_

$V = \langle\ (T_{J1} - 0)$

$V = \langle\ T_{J1}$

We presented this somewhat involved discussion to emphasize that the ice-bath junction output, V_2, is not zero volts. It is a function of absolute temperature.

By adding the voltage of the ice-point reference junction, we have now referenced the TC voltage reading (*V*) to 0°C. This method is very accurate because the ice-point temperature can be precisely controlled. The ice point is used by the National Bureau of Standards (NBS) as the fundamental reference point for their thermocouple tables. Now we can look at the thermocouple tables in Appendix B and directly convert from voltage *V* into temperature.

The copper-constantan thermocouple circuit shown in Figure 7-6 is a unique example because the copper wire is the same metal as the voltmeter terminals. Consider an iron-constantan thermocouple (type J) instead of the copper-constantan (Figure 7-7). The iron wire increases the number of dissimilar metal junctions in the circuit, since both voltmeter terminals become *Cu-Fe* thermocouple junctions.

This circuit will provide moderately accurate measurements as long as the voltmeter (positive) and (negative) terminals (J3 and J4) are the same temperature. The thermoelectric effects of J3 and J4 act in opposition,

$V_1 = V$

Figure 7-7. Iron-constantan thermocouple circuit
Cu J3
J4
J1
Cu
+
_
V
DVM
V_1
Fe
Fe V_2 C
Ice Bath, T = 0°C
J2

if,

$V_3 = V_4$
that is, if
$T_{J3} = T_{J4}$
If both front-panel terminals are not at the same temperature, an error will result. To gain a more precise measurement, you should extend the copper voltmeter leads so the copper-to-iron junctions are made on an "isothermal" (same temperature) block, as shown in Figure 7-8.
The isothermal block is not only a good electrical insulator. It is also a good heat conductor, and this helps to hold J3 and J4 at the same temperature. The absolute block temperature is unimportant because the two
Cu-Fe junctions act in opposition. Thus,
$V = \langle (T_1 - T_{ref})$
The circuit in Figure 7-8 will provide accurate readings, but it is desirable to eliminate the ice bath if possible. One way to do this is to replace the ice bath with another isothermal block, as shown in Figure 7-9.
The new block is at reference temperature T_{ref}, and because J3 and J4 are still at the same temperature we can again show that:
$V = \langle (T_1 - T_{ref})$
Figure 7-8. Using an isothermal block in a thermocouple circuit
Cu
J3
J4
J1
Cu
+
_
V
DVM
V_1
Fe V_2 C
Ice Bath, T = 0°C
J2
Fe
Isothermal Block
Chapter 7 – Temperature Measurement 205
This is still a complicated circuit because we have to connect two thermocouples. Let's eliminate the extra *Fe* wire in the negative (□) lead by combining the *Cu-Fe* junction (J4) and the *Fe-C* junction (J_{ref}). We can do this by first joining the two isothermal blocks (Figure 7-10). We have not changed the output voltage V. It is still as follows:
$V = \langle (T_1 - T_{ref})$
Now we can use the law of intermediate metals to eliminate the extra junction. This empirical "law" states that a third metal (in this case, iron) inserted between the two dissimilar metals of a thermocouple junction will have no effect on the output voltage as long as the two junctions formed by the additional metal are at the same temperature (see Figure 7-11).
Figure 7-9. Eliminating ice bath using isothermal block
Figure 7-10. Joining the isothermal blocks
Cu
J3
J4
J1

Cu
+
_
V
DVM
V_1
Fe V_2 C
J2
Fe
Isothermal Blocks
Cu
J3
J4
J1
Cu
+
_
V
DVM
V_1
Fe V_2 C
J2
Fe
One Isothermal Block

This is a useful result, as it eliminates the need for the iron wire in the negative lead. This can be seen in Figure 7-12. There again, $V = 〈 (T_1 - T_{ref})$, where 〈 is the Seebeck coefficient for a *Fe-C* thermocouple. Junctions J2 and J3 take the place of the ice bath. These two junctions now become the “reference junction.”

Now we can proceed to the next logical step: directly measure the temperature of the isothermal block (the reference junction) and use that information to compute the unknown temperature, T_{J1}. The thermistor is a temperaturemeasuring device whose resistance R_t is a function of temperature. It provides us with a method for measuring the temperature of the reference junction (Figure 7-13). We assume that the junctions J2 and J3 and the thermistor are all at the same temperature because of the design of the isothermal block. Using a digital voltmeter under computer control, we simply do the following:

1. Measure R_t to find T_{ref}, and convert T_{ref} to its equivalent reference junction voltage, V_{ref}.
2. Measure V and subtract V_{ref} to find V_1, and convert V_1 to temperature T_{J1}.

Figure 7-11. Law of intermediate metals
Figure 7-12. Equivalent thermocouple circuit
Metal A Metal B Metal C Metal A Metal C
Cu
J1
Cu
+
_
V
DVM
V_1
C
J3

Isothermal Block
J2
Fe

This procedure is known as "software compensation" because it relies on a computer's software to compensate for the effect of the reference junction. The isothermal terminal block temperature sensor can be any device that has a characteristic that is proportional to absolute temperature: a resistance temperature detector (RTD), a thermistor, or an integrated-circuit sensor.

The logical question is, "If we already have a device that will measure absolute temperature (such as an RTD or thermistor), why do we even bother with a thermocouple that requires reference junction compensation?" The single most important answer to this question is that the thermistor, the RTD, and the integrated-circuit transducer are useful only over a limited temperature range. You can use thermocouples, on the other hand, over a wide range of temperatures. Moreover, they are much more rugged than thermistors (as evidenced by the fact that thermocouples are often welded to metal process equipment or clamped under a screw on the equipment). They can be manufactured easily, either by soldering or welding.

In short, thermocouples are the most versatile temperature transducers available. Furthermore, a computer-based temperature-monitoring system can perform the entire task of reference compensation and software voltage-totemperature conversion. As a result, using a thermocouple in process control becomes as easy as connecting a pair of wires. The one disadvantage of the computer-based approach is that the computer requires a small amount of extra time to calculate the reference junction temperature, and this introduces a small dead time into a control loop.

Figure 7-13. Standard thermocouple measurement circuit
Cu
J1
Cu
+
_
V
DVM
V_1
J3 C
Block at Reference Temperature, T_{ref}
J2 Fe
R_t

Resistance Temperature Detectors

In principle, any material could be used to measure temperature if its electrical resistance changes in a significant and repeatable manner when the surrounding temperature changes. In practice, however, only certain metals and semiconductors are used in process control for temperature measurement. This general type of instrument is called a *resistance temperature detector* or RTD. RTDs are the second most widely used temperature measurement device because of their inherent simplicity, accuracy, and stability.

History of the RTD

In 1821, the same year in which Seebeck made his discovery about thermoelectricity, Sir Humphrey Davy announced that the resistivity of metals showed a marked dependence on temperature. Fifty years later, Sir William Siemens recommended platinum as the element to be used in a resistance thermometer. His choice proved most correct, since platinum is used to this day as the primary element in all high-accuracy resistance thermometers. In fact, the platinum resistance temperature detector, or PRTD, is used today as an interpolation standard from the oxygen point (-182.96°C) to the antimony point (630.74°C). Platinum is especially suited to this purpose because it can withstand high temperatures while maintaining excellent stability and good linearity.

C. Meyers proposed the classical RTD construction using platinum in 1932. He wound a helical coil of platinum on a crossed mica web and mounted the assembly inside a glass tube. This construction minimized strain on the wire while maximizing resistance. Although this construction produced a very stable element, the thermal contact between the platinum and the measured point was quite poor. This resulted in a slow thermal response time. The fragility of the structure limits its use today primarily to that of a laboratory standard.

In a more rugged construction technique, the platinum wire is wound on a glass or ceramic bobbin, as illustrated in Figure 7-14. The winding reduces the effective enclosed area of the coil, which minimizes a magnetic pickup and its related noise. Once the wire is wound onto the bobbin, the assembly is then sealed with a coating of molten glass. The sealing process ensures that the RTD will maintain its integrity under extreme vibration, but it also limits the expansion of the platinum metal at high temperatures. Unless the coefficients

of expansion of the platinum and the bobbin match perfectly, stress will be placed on the wire as the temperature changes. This will result in a straininduced resistance change, which may cause permanent change in the resistance capacity of the wire.

Metal-Film RTDs

In the newest construction technique, a platinum or metal-glass slurry film is deposited or screened onto a small flat ceramic substrate. It is then etched with a laser-trimming system and sealed (see Figure 7-15). The laser makes adjustment cuts to achieve the desired base resistance. The metal-film RTD substantially reduces assembly time and has the further advantage of providing increased resistance for a given size. Because of the technology with which the device is manufactured, the device size itself is small, normally about onehalf inch by one-half inch. This means it can respond quickly to rapid changes

Figure 7-14. Typical RTD – resistance temperature detectors

Figure 7-15. Metal-film RTD

Ceramic Bobbin
Resistance Element
Protective Casing
Platinum Leads
Platinum Leads Substrate
Screen Printed Fired Grid
Adjustment Cuts

in temperature. Film RTDs are currently less stable than wound RTDs, but they are becoming more popular because of their decided advantages in size and low production cost.

The common values of resistance for platinum RTDs range from 10 ∧ to several thousand ohms. The single most common value is 100 ∧ at 0°C. The resistance only changes about 0.4 percent per one degree change in centigrade temperature. This change in resistance with temperature is called the *temperature coefficient* (〈). The standard temperature coefficient of the platinum wire used in RTDs is 0.00385 ∧/°C in Europe and 0.00392 ∧/°C in America. These values are the average slope from 0 to 100°C. Electronic circuits are used to measure this small resistance change with temperature.

RTD Measurement Circuits

The most common method for measuring the resistance of an RTD is to use a Wheatstone bridge circuit. Figure 7-16 shows the arrangement for a two-wire RTD. An electrical excitation current is passed through the bridge, and the RTD and bridge output voltage is an indication of the RTD resistance. The circuit uses a very stable excitation power source, three high-precision resistors that have a very low temperature coefficient, and a high-input impedance amplifier to measure the resistance change of the RTD with changes in temperature.

Figure 7-16. Two-wire RTD bridge circuit

R_1 R_3

R_2

Excitation

Current Source

Output

RTD

Lead Resistance

Wire "A"

Wire "B"

The RTD is generally located on process equipment or piping, and the measurement circuit can be located hundreds of feet from a control room at the process plant. Since both the slope and the absolute value of resistance of a typical RTD are small numbers, the length of the wire from the RTD to the Wheatstone bridge circuit can be significant. This is especially true when we consider that the measurement wires that lead to the sensor may be several ohms or even tens of ohms. A small lead resistance can introduce significant error into the measurement of output temperature. For example, a 10 ∧ lead wire on a field-mounted RTD implies a 10 ∧/0.385∧/°C = 26°C error in a measurement. Even the temperature coefficient of the lead wire can contribute a measurable error.

The standard method for avoiding this problem has been to use a three-wire connection to the Wheatstone bridge measurement circuit, as shown in Figure 7-17.

In the circuit shown in Figure 7-17, if wires A and B are perfectly matched in length, their impedance effects will cancel because each is in an opposite leg of the bridge. The third wire, C, acts as a sense lead and carries a very small current (in the microampere range).

Four-Wire Resistance Measurement

The Wheatstone bridge method of measuring the resistance of an RTD has certain problems associated with it. These problems are solved by the tech-

Figure 7-17. Three-wire RTD bridge

R_1 R_3

R_2

Excitation

Current Source

Output

RTD

Lead Resistance

Wire “C”

Wire “B”

Wire “A”

nique of using a current source along with a remotely located DVM, as shown in Figure 7-18. The output voltage read by the DVM is directly proportional to RTD resistance, so you only need one conversion equation to convert from resistance to temperature. The three bridge resistors are replaced by one RTD. The digital voltmeter measures only the voltage dropped across the RTD and is insensitive to the length of the lead wires.

One disadvantage of a four-wire system is that, obviously, it requires one more wire than a three-wire bridge. However, this is a small price to pay given the increased accuracy of the temperature measurement it provides.

Resistance to Temperature Conversion

The RTD is a more linear device than the thermocouple, but it still requires curve fitting to yield a more precise reading. The Callendar-Van Dusen equation has been used for years to approximate the platinum RTD curve:

(7-10)

where

R = resistance at temperature T

R_o = resistance at T = 0°C

〈 and ™= constants

® = 0 if $T > 0$, or ® is 0.1 (typical) if $T < 0$

Figure 7-18. Four-wire RTD circuit

DVM

Current

Source

Wire 1

Wire 2

Wire 3

Wire 4

RTD

R Ro 〈*Ro T* ™ *T*

100

⎝-------- – 1⎠

⎛ ⎞ *T*

100

⎝--------⎠

– ⎛ ⎞ ® *T*

100

⎝-------- – 1⎠
⎛ ⎞ T3
100
⎝--------⎠
= + – ⎛ ⎞
Chapter 7 – Temperature Measurement 213
You determine the exact values for coefficients 〈, ®, and ™ by testing the RTD at four temperatures and then solving the resulting equations. Typical values for platinum RTDs are as follows:
〈 = 0.00392
™ = 1.49
® = 0 if $T > 0°C$, and ® = 0.1 for $T < 0°C$
Example 7-7 illustrates a typical calculation to obtain the resistance ratio for a platinum RTD.

Thermistors

Like the RTD, the thermistor is also a temperature-sensitive resistor. The name *thermistors* is derived from the term "*therm*ally sensitive re*sistors*," since the resistance of the thermistor varies as a function of temperature. While the thermocouple is the most versatile temperature transducer and the RTD is the most linear, "most sensitive" are the words that best describe thermistors. The

EXAMPLE 7-7
Problem: Calculate the resistance ratio for a platinum RTD with 〈 = 0.00392 and ™ = 1.49 when T = 100°C.
Solution: Since T is greater than 0°C, ® = 0, the Callendar-Van Dusen equation reduces to the following:
So,
R Ro 〈*Ro T* ™ *T*
100
⎝-------- – 1⎠
⎛ ⎞ *T*
100
⎝--------⎠
= + – ⎛ ⎞
R Ro (0.00392)*Ro* 100 1.49 100
100
⎝-------- – 1⎠
⎛ ⎞ 100
100
⎝--------⎠
= + – ⎛ ⎞
$R = R_o + (0.00392)(100)R_o$
R
Ro
------ = 1.392
214 Measurement and Control Basics, Fifth Ed.
thermistor exhibits by far the largest value change with temperature of the three major categories of sensors.
A thermistor's high resistance change per degree change in temperature provides

excellent accuracy and resolution. A standard 2,000-ohm thermistor with a temperature coefficient of 3.9%/°C at 25°C will have a resistance change of 78 ohms per °C change in temperature. A 2000 ∧ platinum RTD would have a change of only 7.2 ohms under the same conditions. So, a standard thermistor is over ten times more sensitive than a RTD. This allows the thermistor circuit to detect minute changes in temperature that could not be observed with an RTD or thermocouple circuit. A thermistor connected to a bridge circuit can readily indicate a temperature change of as little as 0.0005°C.

The cost of this increased sensitivity is loss of linearity, as the curves in Figure 7-19 show. The thermistor is an extremely nonlinear device that is highly dependent on process parameters. Consequently, manufacturers have not standardized thermistor curves to the same extent as they have RTD and thermocouple curves.

You can approximate an individual thermistor curve very closely by using the Steinhart-Hart equation:

(7-11)

Figure 7-19. Comparison of TC, RTD, and thermistor

Thermistor RTD
TC
Voltage or
Resistance
Temperature

1*T*

--- *A B R C*(ln*R*)3 = + ln +

where

T = temperature (K)

R = resistance (∧) of the thermistor

A, *B*, and *C* = curve-fitting constants

You can find the constants *A*, *B*, and *C* by selecting three data points on the published data curve and solving the three simultaneous equations. When you choose data points that span no more than 10°C within the nominal center of the thermistor's temperature range, this equation approaches a remarkable +0.01°C curve fit.

Example 7-8 illustrates a typical calculation to obtain the temperature for a thermistor with a known resistance.

A great deal of effort has gone into developing thermistors that approach a linear characteristic. These are typically three- or four-lead devices that require the use of external matching resistors to linearize the characteristic curve. Modern data acquisition systems with built-in microprocessors have made this type of hardware linearization unnecessary.

The high resistivity of the thermistor affords it a distinct measurement advantage. The four-wire resistance measurement is not required as it is with RTDs. For example, a common thermistor value is 5,000 ∧ at 25°C. With a typical temperature coefficient of 4%/°C, a measurement lead resistance of 10 ∧ produces only a 0.05°C error. This is a factor of five hundred times less than the equivalent RTD error.

Because thermistors are semiconductors, they are more susceptible to permanent decalibration at high temperatures than are RTDs or thermocouples. The use of thermistors is generally limited to a few hundred degrees Celsius, and manufacturers warn that extended exposures, even well below maximum operating limits, will cause the thermistor to drift out of its specified tolerance. Thermistors can be manufactured very small, which means they will respond quickly to temperature changes. It also means that their small thermal mass makes them susceptible to self-heating errors. Thermistors are more fragile than RTDs or thermocouples, and you must mount them carefully to avoid crushing or bond separation.

Integrated-Circuit Temperature Sensors

Integrated-circuit temperature transducers are available in both voltage and current-output configurations (Figure 7-20). Both supply an output that is linearly proportional to absolute temperature. Typical values are one microampere of current per one-degree temperature change in Kelvin (1 μA/K) and ten millivolts per one-degree change in Kelvin (10 mv/K).

EXAMPLE 7-8

Problem: A typical thermistor has the following coefficients for the Steinhart-Hart equation:

$A = 1.1252 \times 10^{-3}/K$

$B = 2.3478 \times 10^{-4}/K$

$C = 8.5262 \times 10^{-8}/K$

Calculate the temperature when the resistance is 4000 Ω.

Solution: Using Equation 7-11, we obtain the following:

$T = 320.4\ K$

Now convert from Kelvin to Celsius:

$T = (320.4 - 273.15)°C$

$T = 47.25°C$

$$\frac{1}{T} = A + B\ln R + C(\ln R)^3$$

$$\frac{1}{T} = 1.1252 \times 10^{-3}/K + (2.3478 \times 10^{-4}/K)(\ln 4000) + (8.5262 \times 10^{-8}/K)(\ln 4000)^3$$

$$\frac{1}{T} = 1.1252 \times 10^{-3}/K + 1.9471 \times 10^{-3}/K + 0.0486 \times 10^{-3}/K$$

$$\frac{1}{T} = 3.1209 \times 10^{-3}/K$$

Except for the fact that these devices provide an output that is very linear with temperature, they share all the disadvantages of thermistors. They are semiconductor devices and thus have a limited temperature range. Integrated-circuit temperature sensors are normally only used in applications that have a limited temperature range. One typical application is in temperature data acquisition systems where they are used for thermocouple compensation.

Radiation Pyrometers

A pyrometer is any temperature-measuring device that includes a sensor and a readout. However, in this section we will discuss only radiation-type pyrometers. A radiation pyrometer is a noncontact temperature sensor that infers the temperature of an object by detecting its naturally emitted thermal radiation. An optical system collects the visible and infrared energy from an object and focuses it on a detector, as shown in Figure 7-21. The detector converts the collected energy into an electrical signal to drive a temperature display or control unit.

The detector receives the photon energy from the optical system and converts it into an electrical signal. Two types of detectors are used: thermal (thermopile) and photon (photomultiplier tubes). Photon detectors are much faster than the thermopile type. This enables you to use the photon type for measuring the temperature of small objects moving at high speed.

Radiation pyrometers are used to measure the temperature of very hot objects without being in contact with them. Molten glass and molten metals during smelting and forming operations are typical of the objects they measure. In selecting the correct radiation pyrometer for an application you must consider

Figure 7-20. Integrated-circuit temperature transducers

DVM

_

a) Current - IC Temperature Sensor b) Voltage - IC Temperature Sensor

10 mV/K DVM

+

_

+

1 mA/K

several factors. In either narrow or wide fields of view, the cross-sectional area can vary greatly. It can be rectangular, circular, and slot shaped, depending on the kind of apertures used in the instrument. In some instruments, a telescopic eye magnifies the radiant energy so much smaller objects at longer distances can be measured. Hot objects as small as 1/16 inch in diameter can be measured with some instruments.

The construction of the instrument components, such as the lens and curved mirrors, control the sight path. The materials of construction determine the optical characteristics of the device. For example, glass does not transmit light well beyond 2.5 microns. It is therefore suitable only for high-temperature applications where high-energy outputs are present. Other common optical materials are quartz (transmitting well to 4 microns) and crystalline calcium fluoride (transmitting well up to about 10 microns). Band pass filters are used in some instruments to cut off unwanted light at certain wavelengths.

Temperature Transmitters

After a sensor detects the temperature, the signal needs to be transmitted to the process control system. The two common methods used are temperature transmitters or direct wiring. In the direct wiring method, the temperature sensor output wires are run the entire distance to the control system or display and there is no signal conversion along the wiring run. In the transmitter method, the sensor is connected a short distance to a transmitter where it's signal is converted to a 4 to 20 mA DC, digital, or wireless signal. The con-

Figure 7-21. Block diagram of radiation pyrometer

Hot Object Mirror
Adjustable
Len Eyepiece
Temperature
Indicator
Detector

Chapter 7 – Temperature Measurement 219

verted output signal is then sent to a control system through transmitter's output wiring or wireless network.

There are several advantages of using the temperature transmitter over directly wiring thermocouples or RTDs to control systems. The digital signal or the 4 to 20 mA output signal from a transmitter is more stable than a sensor signal that is wired directly to a control system, because electrical noise interference has less impact on a 4 to 20 mA or digital signal. Another benefit is that the transmitter offers is improved measurement accuracy over the direct wiring method. For example, sensors can be matched to the transmitter, which improves the accuracy of the temperature measurement and the temperature span can be reduced to match the process operating range of the temperature application.

Most transmitters now use a microprocessor which has improved their performance compared to analog electronic designs. These intelligent transmitters are able to compensate for ambient temperature variations and EMI, and provide cold junction compensation for thermocouples. Some also allow the transmitter to be matched to the output curve of the specific sensor, providing an output that is linear over the temperature range. Microprocessor-based transmitters with digital communications are also able to communicate diagnostic information about the health of the temperature sensor and the transmitter's electronics. The use of digital communications allows the use of a single transmitter to make more than one temperature measurement and transfer the multiple readouts to the control system. There are digital transmitters designed to provide four, eight or more individual temperature measurements.

The reliability, security and ease of programming of digital wireless networks have made these networks an excellent choice for the transfer of temperature data from the sensors to the control system. Since temperature changes in most process are slow, the communications refresh time can be set longer than other types of loops, extending battery life. Also, the noise amplitude in temperature loops is normally small compared to other loops decreasing the number of exception updates triggered by noise which also extends battery life.

٦ـ الاسئلة البعدية

A voltage of 10.10 mv is measured across a type K thermocouple at a 0°C reference. Find the temperature at the measurement junction.

رقم المحاضرة:	١٥
عنوان المحاضرة:	Measurement of Volumes, Mass and Flow Rates
اسـم المدرس:	كازيوه فريق صديق
الفئة المستهدفة :	طلبة المعهد التقني /قسم تقنيات الصناعات الكيمياوية
الهدف العام من المحاضرة :	ادراك وتعليم الطالب لقياس الاحجام والكتل ومعدلات التدفق
الأهداف السلوكية او مخرجات التعلم:	١-ادراك الطالب لقوانين الكتلة والاحجام ٢- السيطرة على معدلات التدفق في الاجهزة
استراتيجيات التيسير المستخدمة	١- التعلم التفاعلي: تشجيع النقاشات والأسئلة لتحفيز التفكير. ٢- العروض العملية: تقديم تجارب حية أو عروض توضيحية للمفاهيم. ٣- التقييم المستمر: تقديم اختبارات قصيرة أو أنشطة تقييمية خلال الدروس. ٤- التغذية الراجعة الفورية: إعطاء ملاحظات مباشرة للطلاب لتحسين الأداء. ٥- التطبيق العملي: تنفيذ مشاريع أو تمارين عملية لمحاكاة الواقع.
المهارات المكتسبة	من اجل صيانة الأجهزة والاستفادة منها مدة اطول
طرق القياس المعتمدة	

٤ ـ الاسئلة القبلية

What is the basic principle used by venturi tubes, flow nozzles, and wedge flow elements to measure flow?

٥- المحتوى العلمي

محتويات الفصل

Flow Measurement

Introduction

The study of fluids in motion, or flow, is one of the most complex branches of engineering. This complexity is reflected in examples such as the flow of a river during a flood or a swirling tornado. Each drop of water in a flooding river and each particle of material in the tornado is governed by the laws of physics, but the equations for the entire flow are very complicated for these situations. Fortunately, idealized models that are simple enough to permit detailed analysis can represent most situations in process control systems that are fairly stable.

This chapter discusses the most common types of flow detection devices encountered in process control. The instruments used to measure flow fall into four general classes: differential pressure, velocity type, positive displacement, and mass. Differential-pressure flowmeters measure flow by inferring the flow rate from the drop in differential pressure (*dP*) across an obstruction in the process pipe. Some of the common *dP* flowmeters are orifice plates, venturi tubes, flow nozzles, wedge flow meters, pitot tubes, and annubars. With velocity devices, the flow rate is determined by measuring the velocity of the flow and multiplying the result by the area through which the fluid flows. Typical examples of velocity devices include turbine, vortex shedding, magnetic, and ultrasonic flowmeters Volumetric or positive-displacement (PD) flowmeters measure flow by measuring volume directly. Positive-displacement flowmeters use high- tolerance machined parts to physically trap pre274

cisely known quantities of fluid as they rotate. Common devices include rotary-vane, oval-gear, and nutating-disk flowmeters. Mass flowmeters measure the mass of the fluid directly. An example is the Coriolis mass flowmeter.

But first, we will discuss the basic principles of flow, then move on to derive the basic equations for flow velocity and volumetric flow before discussing the common types of flow measuring devices and instruments used.

Flow Principles

Our discussion in this chapter will consider only a so-called *ideal fluid*, that is, a liquid that is incompressible and has no internal friction or viscosity. The assumption of incompressibility is usually a good approximation for liquids. A gas can also be treated as incompressible if the differential pressure driving it is low. Internal friction in a fluid gives rise to shearing stresses when two adjacent layers of fluid move relative to each other, or when the fluid flows inside a tube or around an obstacle. In most cases in process control, these shearing forces can be ignored in contrast to gravitational forces or forces from differential pressures.

All flow involves some form of energy. Energy can be expressed in many different forms, including thermal, chemical, and electrical. However, flow measurement focuses on two main types of energy: potential and kinetic. Potential energy (U) is defined as force (F) applied over a distance (d), or

$U = Fd$ (10-1)

Kinetic energy (K) is defined as one-half the mass (m) times the square of velocity of the body in motion, or

(10-2)

Potential Energy

The term *potential energy* probably came from the idea that we give an object the "potential" to do work when we raise it against gravity. The potential energy of water at the top of a waterfall is converted into a kinetic energy of motion at the bottom of the fall.

K 1

2

--$mv2$ =

Potential energy is usually applied to the work that is required to raise a mass against gravity. Force is defined as mass (m) times acceleration (a):

$F = ma$ (10-3)

Therefore, the work (W) required to raise a mass through a height (h) is expressed as follows:

$W = Fh = mgh$ (10-4)

where g is the acceleration of the object due to gravity. The term mgh is called gravitational potential energy, or

$U = mgh$ (10-5)

This energy can be recovered by allowing the object to drop through the height h, at which point the potential energy of position is converted into the kinetic energy of motion.

Work and Kinetic Energy

The work that a force does on a body is related to the resultant change in the body's motion. To develop this relationship further, consider a body of mass m being driven along a straight line by a constant force of magnitude F that is directed along the line. Newton's second law gives the acceleration of a body as follows:

$F = ma$ (10-6)

Suppose the speed increases from $v1$ to $v2$ while the body undergoes a displacement d. From standard analysis of motion, we know that:

(10-7)

or

(10-8)

Since $F = ma$,

(10-9)

$v1\ 2\ v2\ 2 = +\ 2ad$

a

$v2\ 2\ v1\ 2 -$

$2d$

= -----------------

$F\ m$

$v2\ 2\ v1\ 2 -$

$2d$

= -----------------

therefore,

(10-10)

The product Fd is the work (W) done by the force (F) over the distance d. The quantity $1/2mv2$—that is, one-half the product of the mass of the body and the square of its velocity—is called its *kinetic energy* (KE).

The first term on the right-hand side of Equation 10-10, which contains the final velocity $v2$, is the final kinetic energy of the body, $KE2$, and the second term is the initial kinetic energy, $KE1$. The difference between these terms is the change in kinetic energy. This leads to the important result that the work of the external force on a body is equal to the change in the kinetic energy of the body, or

(10-11)

Kinetic energy, like work, is a *scalar* quantity. The kinetic energy of a moving body, such as fluid flowing, depends only on its speed, not on the *direction* in which it is moving. The *change* in kinetic energy depends only on the work ($W = Fd$) and not on the individual values of F and d. This fact has important consequences in the flow of fluid.

For example, consider the flow of water over a dam with height, h. Any object that falls through a height h under the influence of gravity is said to gain kinetic energy at the expense of its potential energy. Let's assume that water with mass m falls through the distance h, converting all its potential energy (mgh) into kinetic energy. Since energy must be conserved, the kinetic energy must equal the potential energy. Therefore,

(10-12)

This equation can be solved for velocity v to obtain the following:

(10-13)

Equation 10-13 shows that the velocity of water at the base of the dam depends on the height (h) of the dam and on gravity (g). Since gravity is constant at about 32 ft/sec 2 or 9.8 m/sec2 on the earth's surface, the velocity depends only on the height h and not on the mass of the flowing fluid. This is

Fd 12

--$mv2$ 2

12

--$mv1$ 2 = –

$W\ KE2 = –\ KE1 = ⊗KE$

$mgh\ mv2$

2

= ----------

$v = 2gh$

Chapter 10 – Flow Measurement 277

an important property in the study of fluid flow. The following example will illustrate this property.

Flow in a Process Pipe

Another example of the relationship between energy and fluid velocity is the flow of fluid in a process pipe of uniform and fixed cross section (A), as shown in Figure 10-1. The differential pressure (⊗P) between the inlet and the outlet causes the fluid to flow in the pipe.

The flow of fluid is maintained by the energy difference between the inlet and the outlet. Let's find the fluid velocity (v) in terms of the inlet pressure $P1$ and the outlet pressure $P2$, assuming no energy loss in the pipe. Since the pipe has a uniform area A, the pressure at the inlet is $P1$ and the pressure at the outlet is

EXAMPLE 10-1

Problem: A valve is opened on the bottom of a storage tank filled to a height of 4 feet with water. Find the discharge velocity of the water just after the outlet valve is opened.

Solution: The velocity can be found from Equation 10-13 as follows:

Figure 10-1. Flow in a pipe

$v = 2gh$

v 2 32ft sec= (Δ 2)(4ft) = 16ft Δ sec

L

(P1, v1)

Flow D

(P2, v2)

278 Measurement and Control Basics, Fifth Ed.

$P2$. The total force at the input is $F1 = P1A$, and the total force at the output is $F2 = P2A$.

The energy (work) required to move the fluid through the distance L is force times distance.

$(F_1 – F_2)L = P_1AL – P_2AL = (P_1 – P_2)AL$

Since *AL* is the volume of the pipe, the work is given by the following:

Work = Energy = $(P_1 – P_2)$ (Volume)

Work = ⊗*P* x *V* (10-14)

The complete energy equation for a flow system must include all possible energy terms, including "internal energy" changes (the energy stored in each molecule of the fluid). This energy includes molecular kinetic energy, molecular rotational energy, potential energy binding forces between molecules, and so on. This internal energy is significant only in laminar flow, where high frictional forces can raise the temperature of the fluid. However, in process control we generally encounter turbulent flow, so we can ignore internal energy in most cases.

Assuming that the flow in Figure 10-1 is steady, let's find the energy relationship for flow in a uniform pipe. We have just shown that the work (energy) done in moving a fluid through a section of pipe is as follows:

Energy = ⊗*PV* (10-15)

This energy is spent giving the fluid a velocity of *v*. We can express this energy of the moving fluid in terms of its kinetic energy (*KE*) as follows:

(10-16)

Since the two energies are the same,

(10-17)

*KE mv*2

2

= ----------

⊗*PV mv*2

2

= ----------

However, by definition, mass *m* is equal to volume *V* time's density 〉, so we can replace mass in the equation with *Vx*〉 to obtain the following:

(10-18)

If we cancel the volume term from both sides of the equation, we obtain:

(10-19)

Then, solving for velocity and taking the square root of both sides of the equation, we obtain the general equation for the velocity of any fluid in a pipe.

(10-20)

This velocity is expressed in terms of the pressure differential and density of the fluid.

Volumetric flow is defined as the volume of fluid that passes a given point in a pipe per unit of time. This is expressed as follows:

$Q = Av$ (10-21)

where

Q = the volumetric flow

A = the cross-sectional area of the flow carrier (e.g., pipe)

v = the fluid's velocity

We can also define mass flow rate (*W*) as the mass or weight flowing per unit time. Typical units are pounds per hour. This is related to the volumetric flow by the following:

(10-22)

where

W = the mass flow rate

〉 = the density

Q = the volumetric flow rate

⊗*PV V*〉*v*2

2

= -------------

⊗*P* 〉*v*2

2

= ---------

v 2⊗*P*

〉

= ----------

W = 〉*Q*

280 Measurement and Control Basics, Fifth Ed.

EXAMPLE 10-2

Problem: Water at 60°F is pumped through a pipe with a 1-in. inside diameter at a flow velocity of 2.0 ft/s. Find the volumetric flow and the mass flow. The density (〉) of water is 62.4 lbs/ft3 at 60°F.

Solution: The flow velocity is given as 2.0 ft/s, so the volumetric flow can be found as follows:

Q = Av

The area of the pipe is given by the following:

so that

The volumetric flow is as follows:

Q = Av

Q = (0.0055 ft2) (2 ft/s) (60 s/min)

Q = 0.654 ft3/min

The mass flow rate is found using Equation 10-22

A □*d*2

4

= ---------

A □(1in. × 1ft Δ 12in.)2

4

-- 0.0055ft2 = =

W = 〉*Q*

W 62.4lb/ft(3) 0.654ft3 = (Δ min)

W = 40.8lb/min

Chapter 10 – Flow Measurement 281

Reynolds Number

The basic equations of flow assume that the velocity of flow is uniform across a given cross section. In practice, flow velocities at any cross section approach zero in the boundary layer adjacent to the pipe wall and vary across the diameter. This flow velocity profile has a significant effect on the relationship between flow velocity and the development of pressure difference in a flowmeter. In 1883, the English scientist Sir Osborne Reynolds presented a paper before the Royal Society that proposed a single dimensionless ratio, now

known as the Reynolds number, as a criterion for describing this phenomenon.
This number *Re*, is expressed as follows:
(10-23)
where
v = the flow velocity
D = the inside diameter of the pipe
〉 = the fluid density
⌠ = fluid viscosity
The Reynolds number expresses the ratio of internal forces to viscous forces.
At a very low Reynolds number, viscous forces predominate and inertial
forces have little effect. Pressure difference approaches direct proportionality
to average flow velocity as well as to viscosity. A Reynolds number is a pure,
dimensionless number, so its value will be the same in any consistent set of
units. The following equations are used in the United States to more
conveniently calculate the Reynolds number for liquid and gas flow through a
process pipe:
(Liquid) (10-24)
or
(Liquid) (10-25)
(Gas) (10-26)
Re
vD〉
⌠
= -----------
Re
3160*QgpmSG*
⌠*D*
= ----------------------------------
Re
50.6*Qgpm*〉
⌠*D*
= ----------------------------
Re
379*Qacfm*〉
⌠*D*
= ---------------------------

where
〉 = density in pounds per cubic foot
D = the pipe inside diameter, is in inches
As shown in Figure 10-2, three flow profile types are encountered in process
pipes: laminar, transitional, and turbulent flow. At high Reynolds numbers,
inertial forces predominate, and viscous drag effects become negligible. At
low Reynolds numbers, flow is laminar and may be regarded as a group of
concentric shells. Moreover, each shell reacts in the manner as viscous shear
on adjacent shells; the velocity profile across a diameter is substantially
parabolic. At high Reynolds numbers flow is turbulent, and eddies form

between the boundary layer and the body of the flowing fluid and then propagate through the stream pattern. A very complex, random pattern of velocities develops in all directions. This turbulent, mixing action tends to produce a uniform average axial velocity across the stream.

EXAMPLE 10-3

Problem: An incompressible fluid is flowing through a process pipe with an inside diameter of 12 inches under a pressure head of 16 in. Calculate the fluid velocity and volumetric flow rate.

Solution: The fluid velocity is found as follows:

where g = 32.2 ft/s2 and h = (16 in.) (1 ft/12 in.) = 1.33 ft.

Thus,

The volumetric flow rate is obtained as follows:

Q = Av

Q = r[(1 ft)2/4] (9.23 ft/s)

Q = 7.25 ft3/s

$v = 2gh$

v 2 32 ft/sec 2 = ( )(1.33 ft) = 9.23 ft/s

Flow is in the laminar region when the Reynolds number is less than 2,000, while flow is generally turbulent if the Reynolds numbers are greater than 4,000. Transitional flow occurs in the range of 2,000 to 4,000. Since the Reynolds number only reflects fluid effects and disregards factors such as pipe bends, pipe fittings, and pipe roughness, the boundaries of laminar, transitional, and turbulent flow are estimates suggested for practical control applications.

In the equation for the Reynolds number for liquid flow, the velocity, *v*, generally varies in a ten-to-one range; the specific gravity generally ranges from 0.8 to 1.2; and the pipe diameter is constant. However, for some liquids, the viscosity can vary from less than one, to thousands of centipoises. So, in most liquid flow applications viscosity has the most effect on the Reynolds number.

While the value of viscosity can be well defined for a given liquid under fixed operating conditions, relatively small changes in temperature can cause orderof-magnitude changes in viscosity. These changes can determine whether the flow is laminar, transitional, or turbulent.

Figure 10-2. Flow profile types

Flow

a) Laminar Flow

Flow

b) Transitional Flow

Flow

c) Turbulent Flow

Example 10-4 illustrates a typical Reynolds number calculation to determine flow type.

In the equation for the Reynolds number for gas flow, the velocity, *v*, generally varies in a ten-to-one range, the density generally varies over a range of less than two to one, and the pipe diameter is constant. However, the viscosity is small and virtually constant in most process applications. So, flow and density have the most effect on the Reynolds number in most gas flow applications.

Since the flow and density are well established in most applications and the viscosity is low, gas flow is turbulent in properly designed process piping

systems.
Example 10-5 demonstrates a typical Reynolds number calculation to determine flow type.

Velocity-Type Flowmeters

In this section we will discuss the four common velocity-type flowmeters: turbine flowmeter, vortex shedding flowmeter, magnetic flowmeter, and ultrasonic flowmeter.

Turbine Flowmeters

The turbine flowmeter, shown in Figure 10-10, provides a frequency or pulse output signal that varies linearly with volumetric flow rate over specified flow ranges. The fluid to be measured enters the flowmeter, then passes through a rotor. The fluid passing the rotor causes it to turn with an angular velocity that is proportional to the fluid linear velocity. Therefore, the volumetric flow rate is linear within given limits of flow rate.

The pickup probe converts the rotor velocity into an equivalent frequency signal. Variable reluctance pickup assemblies are the type most commonly used.

In this system, the meter housing must be nonmagnetic and, so, is usually stainless steel. The rotor must also be stainless steel.

The pickup probe consists of a small, powerful permanent magnet and a coil winding. The field of the magnet is influenced by the moving turbine blades of the rotor, which are made of a permeable material. As a rotor blade passes through the field of the magnet, it provides an easier path for the field. The

Figure 10-10. Turbine flowmeter

Pulses to Flowmeter
Turbine blades
Magnetic Tip
Flow
Magnetic Pickup Coil

field distorts and thus moves across the coil winding. The relative motion between the magnetic field and the coil winding generates an AC voltage, the frequency of which is proportional to flow rate. This can be stated in equation form as follows:

(10-30)

This characteristic of turbine flowmeters, called the meter coefficient (*K*), is used to develop a precisely known number of pulses for a given volume being measured.

Example 10-9 shows the calculation to determine meter coefficient and scaling for a digital turbine flowmeter.

The output signal from a turbine flowmeter is a frequency that is proportional to volumetric flow rate. Each pulse generated by the turbine flowmeter is, therefore, equivalent to a measured volume of liquid. Generally, flow rates are converted into flow totals by totalizer-type instruments. For the totalization to be valid the value of each pulse must be essentially constant. Therefore, the turbine flowmeter must be linear. The turbine flowmeter is generally used

EXAMPLE 10-9

Problem: A digital turbine flowmeter generates 10 pulses per gallon of liquid passing through it. Determine the meter coefficient and calculate the scaling

factor needed to develop an output in which each pulse would represent 100 gallons.
Solution: The meter coefficient is as follows:
The scaling factor is as follows:
(10 pulses/gallon) x (100 gallons) = 1000 pulses
Therefore, a scaling factor of 1,000 is necessary to ensure that the flowmeter's digital circuit generates one output pulse for every 1,000 pulses generated by the magnetic pickup coil.
K Cycles/time
Volume/time
----------------------------------- Pulses
Volume
= = -------------------
K Pulses
Volume
= ------------------- = 10 pulses/gallon
296 Measurement and Control Basics, Fifth Ed.
over its linear range. Totalization is also used for turbine flowmeters that are linear over only a part of the operating range.

Totalizers are available in two general configurations. One form simply either totalizes pulses or does the necessary scaling in direct-reading units. (Scaling means factoring the frequency information so each pulse is equal to a unit volume or decimal part of a volume.) The second configuration not only totalizes but also predetermines the number of counts or unit volumes that are proportional to a given batch size. It then provides a signal, generally a contact closure, to control the process. Batching totalizers that have a ramping function provide an analog output to (1) open a control valve to a given position, (2) control volumetric flow rate, and (3) program the shutdown of the valve to some reduced flow rate at a predetermined point in the batch. This rate is then maintained until the process is terminated.

The flow rate can be indicated digitally or in analog form. Digital counters that have an adjustable time base indicate flow rate either in terms of frequency or in direct-reading units (such as gallons per minute), depending on the time base that has been established. Analog indicators require an analog signal that is proportional to frequency.

Vortex Shedding Flowmeter

The vortex shedding flowmeter is shown in Figure 10-11. Its operating principle is fairly simple. As fluid flows past a bluff body, or shedder, at low velocity, the flow pattern remains streamlined. However, as velocity increases, the fluid separates from each side of the shedder and swirls to form vortices downstream of the shedder. A vortex is an area of swirling motion with high local velocity and thus lower pressure than the surrounding fluid. The amount of vortex generation is directly proportional to the velocity of the fluid. You can, therefore, use the relationship $Q = Av$ to obtain the flow rate.
A pressure sensor that is mounted on the downstream side of the flow shedder detects the pressure that is exerted on the shedder by the formation of vortices. The signal from the pressure sensor is converted into a calibrated flow signal by an electronic circuit in a flowmeter.

Magnetic Flowmeters
The magnetic flowmeter is constructed of a nonmagnetic tube that carries the flowing liquid, which must have a minimum level of conductivity. SurroundChapter 10 – Flow Measurement 297
ing the metering tube are magnetic coils and cores that provide a magnetic field across the full width of the metering tube when electric current is applied (see Figure 10-12). The fluid flowing through the tube is the conductor, and as the conductor moves through the magnetic field a voltage is generated that is proportional to the fluid velocity, which in turn is proportional to the volumetric flow rate. This voltage is perpendicular to both the magnetic field and to the direction of the flowing liquid.

Figure 10-11. Vortex shedding flowmeter

Figure 10-12. Magnetic flowmeter

Bluff Body Pressure Sensor
Flow
Vortex Area
Variable Flow Out
Conductive Fluid In
Sensing Electrodes
Field Coils
Magnetic
D
Process Pipe
Inside Diameter (D)
Magnetic Field B
Electric Field E

298 Measurement and Control Basics, Fifth Ed.

Magnetic flowmeters use Faraday's law of induction to measure flow. This law states that relative motion at right angles between a conductor and a magnetic field will develop a voltage in the conductor. The induced voltage is proportional to the relative velocity of the conductor and the magnetic field. This is the principle used in DC and AC generators. The most common magnetic flowmeters are a modified form of AC generators. In the magnetic flowmeter, the fluid itself must have some minimum conductivity and acts as the conductor.

Fluid is the conductor in the magnetic flowmeter shown in Figure 10-12. The fluid's length is equivalent to the inside diameter of the flowmeter (*D*). The fluid conductor moves with an average velocity (*v*) through a magnetic field (*B*). The volumetric flow (Q) is proportional to the electric field (*E*) that the constant magnetic field induces in the conductive fluid. The mathematical relationship for the magnetic flowmeter is as follows:

(10-31)

where
C = the meter constant
B = the magnetic field strength
D = the diameter of the flowmeter

The magnetic field generated lies in a plane that is mutually perpendicular to the axis of the instrument and the plane of the electrodes. The velocity of the fluid is along the longitudinal axis of the detector body. The voltage induced within the fluid is perpendicular to both the velocity of the fluid and the magnetic field, and is generated along the axis of the meter electrodes. The

fluid can be considered as a series of fluid conductors that are moving through the magnetic field. An increase in flow rate will result in a greater relative velocity between the conductor and the magnetic field, and as a result a greater instantaneous value of voltage will be generated.
The instantaneous voltage generated at the electrodes represents the average fluid velocity of the flow profile. The output signal of the meter is equal to the continuous average volumetric flow rate regardless of flow profile. Therefore, magnetic flowmeters' measurements are independent of viscosity changes. It is always absolutely essential that the meter be full because the meter senses velocity as being analogous to volumetric flow rate.
Q CE
BD
= --------
Chapter 10 – Flow Measurement 299
Ultrasonic Flowmeters
The operating principle of ultrasonic flowmeters is to measure the velocity of sound as it passes through the fluid flowing in a pipe. The most common approach is shown in Figure 10-13. In this configuration piezoelectric crystals (barium titanate or lead zirconate-titanate) are used as sound transmitters to send acoustic signals through the fluid flowing in the pipe to receivers that are also piezoelectric crystals. The fluid flows through the pipe at a velocity v. The distance between each transmitter-receiver pair is d. The velocity of the sound through the fluid is v, and the path of the sound lies at an angle 〈 from the pipe wall.
The velocity of sound from transmitter A to receiver B (increased by the fluid velocity) is $v_s + v$ cos 〈, and its frequency is as follows:
(10-32)
The velocity of sound from transmitter B to receiver A (reduced by fluid velocity) is given by $v_s - v$ cos 〈, and its frequency is as follows:
(10-33)
Figure 10-13. Ultrasonic flowmeter
d
Flow
Piezoelectric Transmitter
Receiver
Receiver
Piezoelectric Transmitter
f_a
$v_s + v\cos〈$
d
= ---------------------------
f_b
$v_s - v\cos〈$
d
= ---------------------------
300 Measurement and Control Basics, Fifth Ed.
The difference between the two frequencies or beat frequency ($\otimes f = f_a - f_b$) is given by:
(10-34)

Since 〈 and *d* are constant, you can obtain the flow velocity by measuring this beat frequency.
Solving Equation 10-34 for flow velocity we obtain the following:
(10-35)
You obtain the volumetric flow rate by multiplying the flow velocity by the cross-sectional area of the pipe.
The beat frequency is measured by using an electronic mixer. The purpose of the mixer is to translate the higher frequencies to a lower frequency level, where it is possible to amplify and select them more efficiently. In general, the design of a mixer is similar to that of a radio- frequency (*rf*) amplifier except that the latter includes an oscillator frequency. The combination of two oscillators and a mixer is referred to as a beat-frequency oscillator (*bfo*). Example 10-10 shows how to calculate fluid velocity for an ultrasonic flowmeter.
EXAMPLE 10-10
Problem: Given a beat frequency (⊗f) of 100 cps for an ultrasonic flowmeter, the angle (〈) between the transmitters and receivers is 45o and the sound path (*d*) is 12 in. Calculate the fluid velocity in feet per second.
Solution: Using Equation 10-34 for the velocity based on the beat frequency gives us the following:
⊗*f* 2*v*cos〈
d
= -------------------
v (⊗*f*)(*d*)
2cos〈
= ------------------
v (⊗*f*)(*d*)
2cos〈
= ------------------
v (100 cycles/sec)(1 ft)
2cos45°
= ---
v = 70.7 ft/s

Ultrasonic flowmeters are normally installed on the outside of liquid-filled pipes. This is so the measuring element is nonintrusive and will not induce a pressure drop or disturbance into the process stream. Ultrasonic flowmeters generally cost more than standard flow measuring devices, such as orifice plates or venturi tubes. However, they can be easily attached to the outside of existing pipes without having to shut down the process or use special pipe sections or isolation valves. For that reason, their overall cost compared to conventional flowmeters is generally less than alternative meters in the larger pipe sizes.

Positive Displacement Flowmeters

Positive displacement (PD) flowmeters continuously entrap a known quantity of fluid as it passes through the meter. Since both the number of times the fluid is entrapped and the volume of the entrapped fluid are known, you can easily determine the amount of fluid that has passed through the meter. This section discusses the three common types of PD flowmeters encountered in process control: rotary vane, oval gear, and nutating disk.

Rotary Vane PD Flowmeters

Rotary vane PD flowmeters are widely used in liquid processes where accuracy is important. This type of flowmeter converts the entrapment of liquid into a rotational velocity that is proportional to the flow through the device. The forces exerted by the flowing fluid rotate blades in the flowmeter on a center shaft. The blades and inside body of the flowmeter are machined to close tolerances during manufacture since they must form a tight seal with each other over the life of the flowmeter.

Oval Gear PD Flowmeters

Oval gear PD flowmeters are generally used on very viscous liquid, which is difficult to measure using other flowmeters. The liquid flow through the flowmeter applies a force on a pair of oval gears, which causes them to rotate.

As Figure 10-14 shows, in position 1 uniform forces are applied equally on the top and bottom of oval gear B, so this gear does not rotate. Rotor A has entrapped a known quantity of liquid between the rotor and the meter body, and there is a balanced force on the top of the gear. However, there is force on the bottom of gear A, which causes it to rotate clockwise (CW). This causes gear B to rotate in a counterclockwise (CCW) direction to position 2.

302 Measurement and Control Basics, Fifth Ed.

In position 2, fluid enters the space between gear B and the flowmeter body, as the fluid that was entrapped between gear A and the body simultaneously leaves the area of entrapment. The higher upstream pressures oppose the lower downstream pressures at the ends of gear A and gear B. This causes both gears to continue to rotate in CW and CCW directions, respectively, to position C.

In position 3, a known amount of fluid has been entrapped between gear B and the flowmeter body. This operation is then repeated, with each revolution of the gears representing the passage of four times the amount of fluid that fills the space between the gear and the flowmeter body. Therefore, the fluid flow is directly proportional to the rotational velocity of the gears.

Nutating Disk PD Flowmeters

Nutating disk PD flowmeters are generally used in water service to obtain low-cost flow measurement where high accuracy is not required. The nutating disk flowmeter uses a cylindrical measurement chamber, in which a disk is allowed to wobble, or nutate, as fluid flows through the flowmeter, causing the spindle to rotate. This rotation can be used to drive an indicator or transmitter. Since this PD flowmeter entraps a fixed amount of fluid each time the spindle is rotated, the rate of flow is directly proportional to the rotational velocity of the spindle.

Coriolis Mass Flowmeters

The operating principle of Coriolis mass flowmeters is based on the force exerted by the Coriolis acceleration of a fluid. The flowmeter consists of a

Figure 10-14. Oval gear PD meter

A

B

Position 1

A
B B
A
Position 2 Position 3
Trapped Liquid

vibrating tube in which the Coriolis acceleration is created and measured. A typical flow tube is shown in Figure 10-15.
The flow tube is designed and built to have predictable vibration characteristics. A drive assembly connected to the center of the tube causes the tube to twist as shown in Figure 10-15. This vibrates the tube. Position-sensing coils on each side of the flow tube sense this twisting. Since the frequency of the vibration of the tube varies with the density of the fluid inside the tube, the computer inside the electronics unit of the Coriolis flowmeter can calculate a density value. Coriolis flowmeters can be used on virtually any liquid or gas that flows at a mass great enough to operate the meter.

٦ـ الاسئلة البعدية

A digital turbine flowmeter generates 2 pulses per gallon of liquid passing through the meter. Calculate the meter coefficient, and calculate the scaling factor that is necessary to develop an output in which each pulse would represent 10 gallons.

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