

FIRST-ORDER AND SECOND-ORDER SYSTEM

**Product Code
320B**

Instruction manual



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Description

The set up is designed to study of transient response of first-order and second-order systems.

First-order system:

- 1) Step response of thermometer
- 2) Step response of thermo well
- 3) Sinusoidal response of thermo well

Second-order system:

- 1) Step response of mercury manometer
- 2) Step response of manometer

Setup consists of 'U' tube manometer, heating bath, thermometer, thermo well, beeper for recording observations and timer for heater on-off operation. The components are mounted on base plate. The set up is tabletop mountable.

Specifications

Product	First-order and second-order system
Product code	320A
Thermometer	Range -10 – 0 – 100 ⁰ C
Thermometer with thermowell	Range -10 – 0 – 100 ⁰ C
'U' tube manometer	Tube ID 5mm
'U' tube manometer	Tube ID 22mm
Heating bath	Size 1.25BSP, 315mmL, SS304.
Heater	Type Electrical 2 coil, Capacity 3 KW
Timer	Type Cyclic
Beeper	Time setting Range 2-10sec
Mini compressor	Type Diaphragm
Overall dimensions	1000Wx225Dx485H mm

Shipping details

Gross volume 0.20m³, Gross weight 54kg, Net weight 27kg

Installation requirements

Size: 800Wx800Dx750H in mm

Electric supply

Provide 230 +/- 10 VAC, 50 Hz, single phase electric supply with proper earthing. (Neutral – Earth voltage less than 5 VAC)

- 5A, three pin socket with switch (2 No.)

Water supply

Continuous, clean and soft water supply @100 LPH with suitable drain arrangement.

Support table

Installation Commissioning

INSTALLATION

- Unpack the box(es) received and ensure that all material is received as per packing slip (provided in instruction manual). In case of short supply or breakage contact Apex Innovations / your supplier for further actions.
- Insert thermometers on the heating bath.
- Connect mini compressor to the manometer setup.
- Water supply: Drain the supply water line for few minutes to ensure clean water is received. Then connect water supply to the set up.
- Electric supply: Before connecting electric supply ensure that supply voltage is 230 V AC and earth neutral voltage is less than 5 V Ac.

COMMISSIONING

- Fill mercury in 'U' tube manometer (dia 8 mm) and water in other manometer (dia 26 mm).
- Switch on mini compressor and ensure that it is working OK.
- Start water supply from tap connection.
- Set the timer on time @30 seconds and off time @30 seconds.
- Open the hose cock of heating bath and switch on the mains and ensure that water is heated up.
- Set the beeper for @ 3 seconds time interval.

NOTE: For longer shut down, remove water from the supply tank and clean it.

Troubleshooting

Note: For component specific problems refer components' manual

Problems	Possible causes / remedies
Temperature does not rise	<ul style="list-style-type: none">• Burnt heater coil• Check relay and timer operation.• Clean relay contacts to remove any carbon on the contact tips.
No beeps from beeper	<ul style="list-style-type: none">• Check battery cell voltage and replace.

Components used

Components	Details
Thermometer	Make Oxford, Range -10.0.100 ⁰ C, Mercury filled
Timer	Make Selectron, Model 55C – T8, Contact 5A, 230VAC/28VDC.
Heater	Make Roxy, Type 3.0 kW, 2 coil, Size 1.25" BSPx10" L
Beeper	Make Apex, Model AX-301, Range 2-10second.
Contact realy	Make Leone, Model P40FC – 1C, Supply – 240V AC, AC240V – 580 ohms, Contact 40A, 250VAC
Mini compressor	Make High speed appliances, model HS-SD-01, Type diaphragm

Packing slip

Box No.1/3	Size W475xD500xH560 mm; Vol:0.06m ³	Gross weight: 25 kg Net weight: 12 kg
1	Set up assembly	1 No
2	Instruction manual CD (Apex)	1 No
Box No.2/3	Size W1150xD350xH150 mm; Volume:0.08m ³	Gross weight: 21 kg Net weight: 10 kg
1	Manometer setup assembly	1 No
Box No.3/3	Mini Compressor, Volume:0.06m ³ Size W300xD225xH300 mm; Volume:0.02m ³	Gross weight: 8kg Net weight: 5 kg
1	Mini compressor assembly	1 No

Warranty

This product is warranted for a period of 12 months from the date of supply against manufacturing defects. You shall inform us in writing any defect in the system noticed during the warranty period. On receipt of your written notice, Apex at its option either repairs or replaces the product if proved to be defective as stated above. You shall not return any part of the system to us before receiving our confirmation to this effect.

The foregoing warranty shall not apply to defects resulting from:

Buyer/ User shall not have subjected the system to unauthorized alterations/ additions/ modifications.

Unauthorized use of external software/ interfacing.

Unauthorized maintenance by third party not authorized by Apex.

Improper site utilities and/or maintenance.

We do not take any responsibility for accidental injuries caused while working with the set up.

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Experiments

1. STUDY OF STEP RESPONSE OF THERMOMETER

Theory

A thermometer bulb is a first-order system, whose response can be described by a first-order linear differential equation. The dynamic response of first-order type instruments to a step change can be represented by

$$T \frac{d\theta}{dt} + \theta = \theta_F$$

Where θ = temperature indicated by thermometer

θ_F = Final steady state temperature

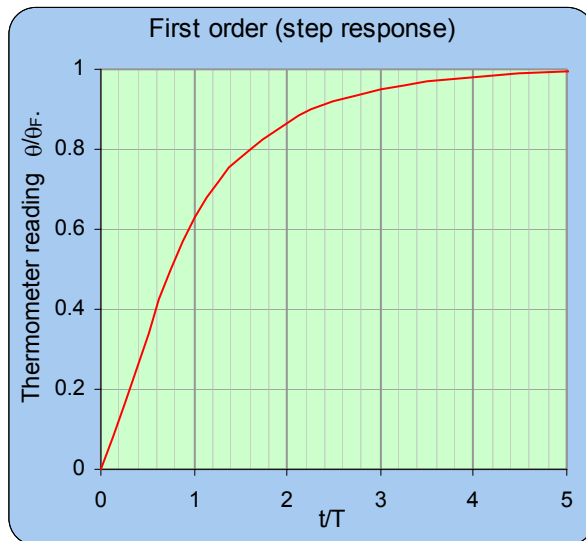
t = time

T = time constant

The linear first order differential has the particular solution for given initial conditions,

$$\frac{\theta}{\theta_F} = 1 - e^{-t/T}$$

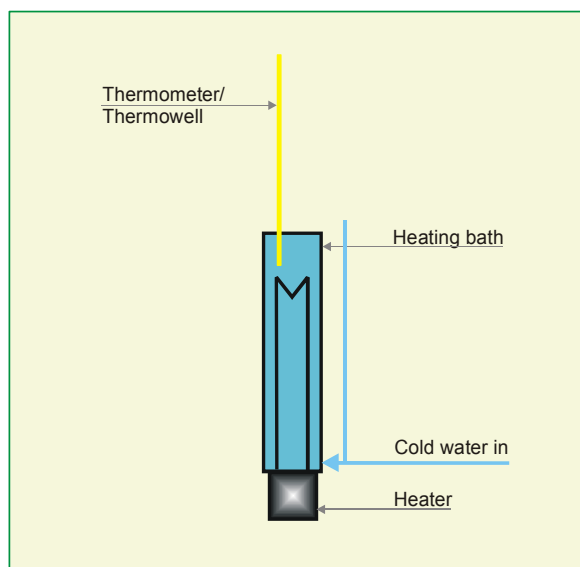
Which represents a single exponential response as shown below.



The time constant T is the time required to indicate 63.2% of the complete change. The time constant T is numerically equal to the product of resistance and capacitance.

Procedure

Prepare the set up as shown below.



- Fill the heating bath with clean water by opening the inlet valve of heating bath.
- Switch on beeper and set beep interval to 3 seconds.
- Ensure that cyclic timer is set to 30 seconds on time and 30 seconds off time. Switch on Mains to heat the water in heating bath to its boiling point. Switch off the mains.
- The water in heating bath is now near its boiling point. Insert the thermometer in heating bath suddenly after noting its initial temperature.
- Note the thermometer reading at each beep interval till the temperature reaches at steady state.
- Switch off beeper and fill up the readings observed in "Observations" below.

Observations

- 1) Initial temperature ($^{\circ}\text{C}$)
- 2) Final temperature ($^{\circ}\text{C}$)

Sr. No.	Time (sec)	Actual temperature ($^{\circ}\text{C}$)
1		
2		
3		
..		

Calculations

1. Step change = Final temp. – Initial temp.
2. Value of 63.2% of step =
 $0.632 \times (\text{Final temp.} - \text{Initial temp.}) + \text{Initial temp.}$
3. Plot the graph of Actual temperature V_s time and note the value of time at 63.2% of step change. This value is observed time constant of the thermometer.
4. Calculate theoretically predicated temperature by following equation:

Theoretical temp. =

$$\text{Initial temp.} + (\text{Step change} \times (1 - \exp(\frac{-1 \times \text{Time}}{\text{Time constant (From graph)}})))$$

5. Plot the graph of Theoretical temperature V_s time on the same graph plotted above.

Sample calculations & results

Refer MS Excel program for calculation and graph plotting.

Comments

Note that observed step response fairly tallies with theoretical step response.

2. STUDY OF STEP RESPONSE OF THERMOWELL

Theory

A thermometer in experiment no.1 is added with additional resistance (thermo-well) at its bulb to increase its time constant. The system can generally be considered as first order system and response can be described as a first-order linear differential equation.

(Refer theory part described in experiment 1)

Procedure

Refer the procedure described in experiment 1. (Use thermo-well instead of thermometer)

Observations

Refer observation part described in experiment 1.

Calculations

Refer calculations part described in experiment 1.

Sample calculations & results

Refer MS Excel program for calculation and graph plotting.

Comments

Note that observed step response fairly tallies with theoretical step response. Also note that the time constant of thermo-well is more than thermometer.

3. STUDY OF SINUSOIDAL RESPONSE OF THERMO WELL

Theory

The dynamic response of first-order type instruments to a sinusoidal change can be represented by

$$T \frac{d\theta}{dt} + \theta = A \sin \omega t$$

Where θ = indicated temperature

t = time

T = time constant

A = amplitude of cycle of measured variable

ω = circular frequency of cycle

A solution with given initial conditions and with the transient terms omitted is,

$$\left[\frac{\theta}{A} \right]_{ss} = \frac{1}{\sqrt{1 + \omega^2 T^2}} \sin(\omega t - \phi)$$

When $\phi = \arctan \omega T$ = lag angle and the subscript ss denotes steady state.

This equation shows that:

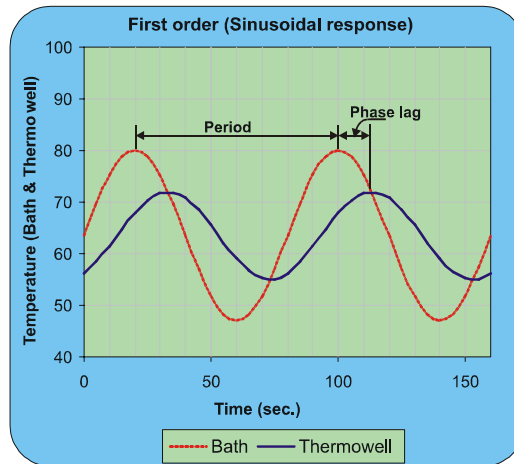
- 1 The output is a sine wave with a frequency ω equal to that of the input signal
- 2 The instrument lags the measured variable by a geometric angle ϕ where

$$\phi = \tan^{-1}(\omega T)$$

- 3 The amplitude is reduced or attenuated. The ratio of output amplitude to input

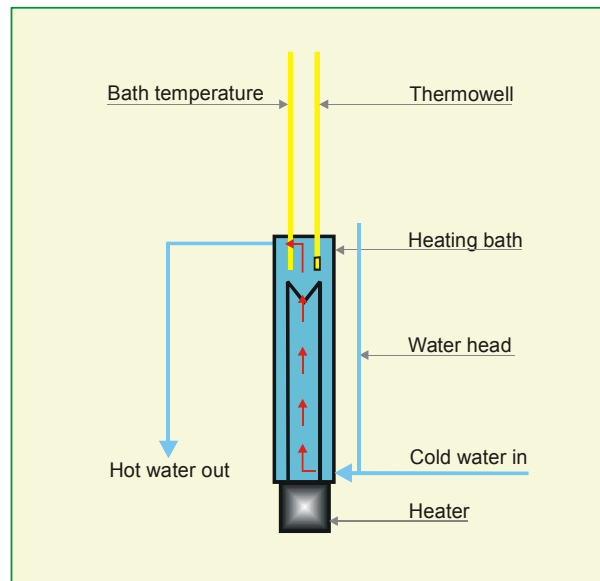
amplitude is $\frac{1}{\sqrt{1 + \omega^2 T^2}}$

To investigate the response of a first-order system to a sinusoidal forcing function, a response of thermo well will be considered in a sinusoidal temperature bath. The general response shall be as shown below.



Procedure

Prepare the set up as shown below.



- Start the clean water supply by opening the inlet valve of heating bath and maintain constant water flow through the heating bath. Keeping constant level in "Water head" indication tube can ensure this.
- Insert the thermometer and thermo well in heating bath.
- Ensure that cyclic timer is set to @30 seconds on time and @30 seconds off time. Switch on Mains to heat the water in heating bath.
- After some time observe sinusoidal response of the heating bath temperature on thermometer. The amplitude (temperature range) can be changed by adjusting water flow rate and period can be changed by adjusting on time, off time of the cyclic timer. (Period = On time + off time)
- At steady state note amplitude ratio and phase lag (Refer observations)

Observations

- 1) Maximum bath temperature ($^{\circ}\text{C}$)
- 2) Minimum bath temperature ($^{\circ}\text{C}$)
- 3) Period of oscillation (sec)
- 4) Maximum thermo well temperature ($^{\circ}\text{C}$)
- 5) Minimum thermo well temperature ($^{\circ}\text{C}$)
- 6) Observed phase lag (sec)

Calculations

Equations used:

$$1. \text{ Input amplitude} = \frac{\text{Maximum bath temp.} - \text{Minimum bath temp.}}{2} \quad \dots^{\circ}\text{C}$$

$$2. \text{ Frequency of oscillation} = \frac{2 \times \pi}{\text{Period of oscillation}} \quad \dots \text{Rad/sec}$$

$$3. \text{ Output amplitude} = \frac{\text{Maximum thermowell temp.} - \text{Minimum thermowell temp.}}{2} \quad \dots^{\circ}\text{C}$$

$$4. \text{ Amplitude ratio} = \frac{\text{Output amplitude}}{\text{Input amplitude}}$$

$$5. \text{ Time constant from amplitude ratio} =$$

$$\sqrt{\frac{1 - \text{Amplitude ratio}^2}{\text{Amplitude ratio}^2 \times \text{Frequency of oscillation}^2}} \quad \dots \text{Sec}$$

$$6. \text{ Phase lag} = \frac{\text{Observed phase lag} \times 360}{\text{Period of oscillation}} \quad \dots \text{Deg.}$$

$$7. \text{ Time constant from phase lag} = \frac{\tan(\text{Phase lag})}{\text{Frequency of oscillation}} \quad \dots \text{Sec}$$

Graph:

Plot the graph of bath & thermo well temperature Vs time to note phase lag and amplitude ratio.

Sample calculations & results

Refer MS Excel program for calculation.

Comments

Compare the time constant of thermo well obtained by step response method and comment.

4. STUDY OF STEP RESPONSE OF MERCURY MANOMETER

Theory

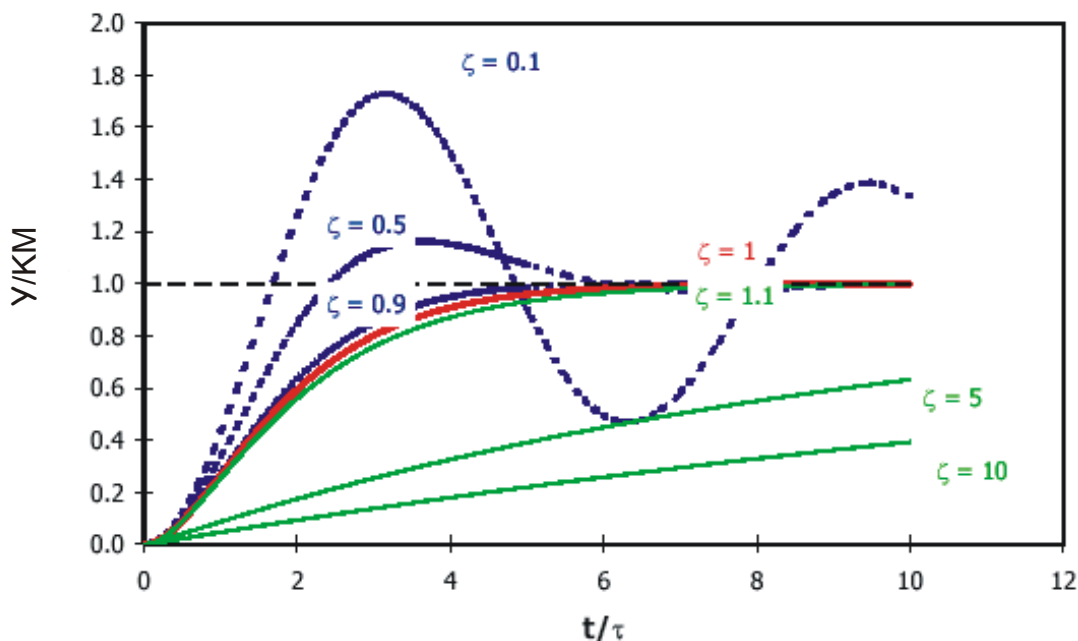
The dynamic response of a second order system to a step change can be described by a second-order differential equation.

The solutions to above equation involve three cases: an under damped condition [$\zeta < 1$], critical damped condition [$\zeta = 1$] and over damped condition [$\zeta > 1$].

The response for under damped system [i.e. $\zeta < 1$] can be written as:

$$y(t) = KM \times \left\{ 1 - e^{-\zeta t/\tau} \left[\cos\left(\frac{\sqrt{1-\zeta^2}}{\tau} t\right) + \frac{\zeta}{\sqrt{1-\zeta^2}} \sin\left(\frac{\sqrt{1-\zeta^2}}{\tau} t\right) \right] \right\} \quad \text{.....1}$$

Following figure shows response of second order system for different damping coefficient.



In case of manometer:

$y(t)$ = response at any time t after step change (deviation value).

K = Gain factor = 1

M = magnitude of step change

$$\text{Damping coefficient } (\zeta) = \frac{8L\mu}{\rho g D^2} \sqrt{\frac{2g}{L}} \quad \text{.....2}$$

(Where L = Column length in meter,

μ = Dynamic viscosity in Kg/m.s.

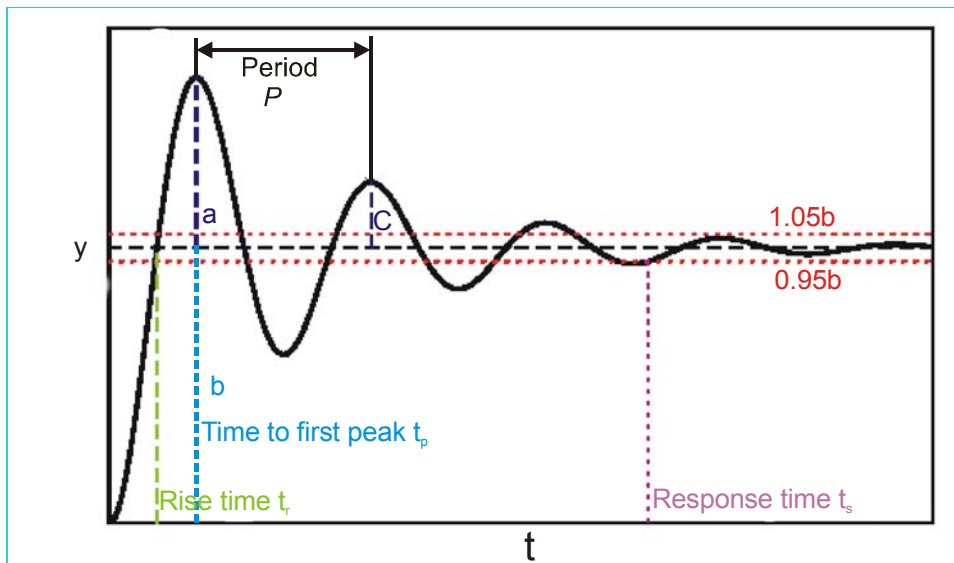
ρ = Mass density of the manometer fluid in kg/m³,
 D = tube diameter in m,
 g = Gravitational acceleration in m/sec²)

$$\text{Characteristics time } (\tau) = \frac{2\pi}{\omega_n} \text{ in sec.} \quad \dots\dots 3$$

$$\text{Frequency of damped oscillation } (f) = \frac{\omega_n \times \sqrt{1-\zeta^2}}{2\pi} \text{ in cps.} \quad \dots\dots 4$$

$$(\text{Where Natural frequency } (\omega_n) = 2\pi\sqrt{\frac{2g}{L}} \text{ in rad/sec}) \quad \dots\dots 5$$

- Performance characteristics for the step response of an under damped system is shown below



1. Rise time = t_r is the time the indicated value takes to first reach the new steady-state value.
2. Time to first peak = t_p is the time required for the indicated value to reach its first maximum value.
3. Response/settling time = t_s is defined as the time required for the indicated value to reach and remain inside a band whose width is equal to $\pm 5\%$ of the total change in θ . The term 95% response time sometimes is used to refer to this case. Also, values of $\pm 1\%$ sometimes are used.
4. Decay ratio (DR) = c/a (Where c is the height of the second peak).

$$DR = \text{Exp}\left(\frac{-2 \times \pi \times \zeta}{\sqrt{1-\zeta^2}}\right) \quad \dots\dots 6$$

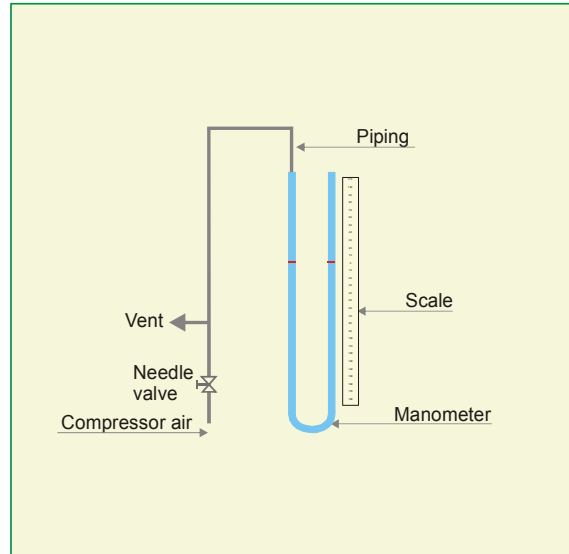
$$\text{Overshoot (OS)} = a/b = \sqrt{\text{Decay ratio}} \quad \dots\dots 7$$

6. Period of oscillation = P is the time between two successive peaks or two successive valleys of the response.

$$P = \frac{2\pi}{\omega_n \times \sqrt{1-\zeta^2}} \quad \dots\dots 8$$

Procedure

Prepare the set up as shown below.



- Ensure that mercury level in manometer is set at '0' on the scale.
- Close vent connection by putting finger on it.
- Adjust the needle valve and vent to raise the mercury level to @200mm from '0' level.
- Note the mercury level reading and quickly open the vent to apply step change. Note the top peak and bottom peak readings. Also simultaneously note the period of oscillation. (This can be noted by measuring time required for 4-5 oscillations and then calculating for each oscillation)
- Repeat process 2-3 times for different step changes.

Observations

Constants:

Manometer fluid = Mercury
Dynamic viscosity (μ) = 0.0016Kg/m.s.
Mass density (ρ) = 13550Kg/m³.
Column length (L) = 0.760m
Tube diameter (d) = 0.005 meter
Step change (mm):
Period of oscillation (sec):

Sr. No.	Actual response* (mm)	Period of oscillation** (sec)
1		
2		
3		
4		

*: Note peak values observed during oscillations.

**: Measure the period of 4-5 oscillations and note average time required for each oscillation.

Calculations

- Calculate natural frequency of oscillations using equation no. 5
- Calculate damping coefficient using equation no. 2
- Calculate period of oscillations using equation no. 8

- Calculate decay ratio using equation no. 6
- Calculate overshoot using equation no. 7
- Calculate frequency of damped oscillations using equation no. 4
- Calculate characteristics time using equation no. 3
- Calculate theoretical response for different time values using equation no.1

Graphs

Plot the graphs of Actual & Theoretical response V_s Time.

Sample calculations & results

Refer MS Excel program for calculation and graph plotting.

Comments

Comment upon the deviations observed in actual and theoretical response.

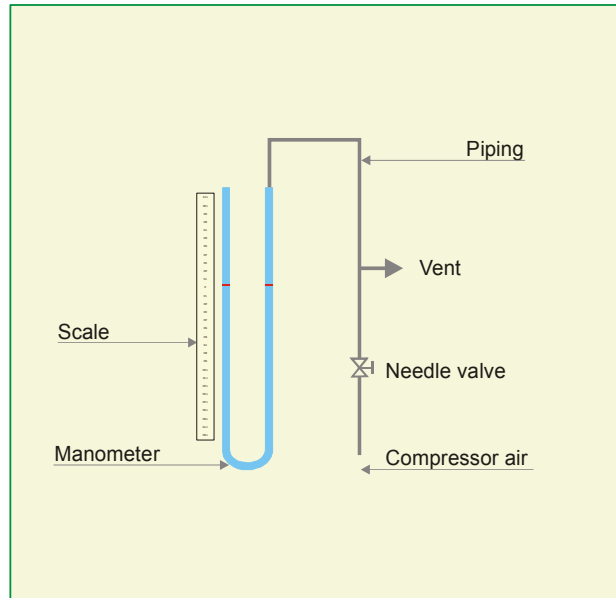
5. STUDY OF STEP RESPONSE OF WATER MANOMETER

Theory:

Refer the theory described in experiment 4.

Procedure

Prepare the set up as shown below.



- Ensure that water level in manometer is set at '0' on the scale.
- Close the vent of water manometer by putting hand on it.
- Adjust the needle valve and vent to deflect the water column to @ 450mm from '0' level.
- Note the water level reading and quickly open the vent to apply step change. Note the top peak and bottom peak readings. Also simultaneously note the period of oscillation. (This can be noted by measuring time required for 4-5 oscillations and then calculating for each oscillation)
- Repeat process 2-3 times for different step changes.

Observations

Constants:

Manometer fluid	= water
Dynamic viscosity (μ)	= 0.001Kg/m.s.
Mass density (ρ)	= 998Kg/m ³

Column length (L) = 1.050m
Tube diameter (d) = 0.022 meter
Step change (mm):
Period of oscillation (sec):

Sr. No.	Actual response*(mm)	Period of oscillation**(sec)
1		
2		
3		
4		

*: Note peak values observed during oscillations.

** : Measure the period of 4-5 oscillations and note average time required for each oscillation.

Calculations

Refer calculations part described in experiment 4.

Graphs

Plot the graphs of Actual & Theoretical response V_s Time.

Sample calculations & results

Refer MS Excel program for calculation and graph plotting.

Comments

Comment upon the deviations observed in actual and theoretical response.

Air Compressor (Mini)



Mini air compressor designed for all type of instruments & equipments and many similar applications. The mini air compressor is designed for continuous operations.

Technical specifications

Model	HS-SD-01
Make	High Speed Appliances
Type	Diaphragm
Supply volt/Hz/phase	230/60/Single phase
HP	1/8
Pressure Max.	30 Psig.
Size	250x115Wx190mmh.
Weight	5 Kg.

Troubleshooting

Problem	Check
Motor does not rotate	Check power supply. Check supply voltage. Replace condenser.
Air pressure problem	Check diaphragm and damage it is change. Air filter clean by Kerosene. Check connection joint and sealing. Check connection hole.

Manufacturer's address

If you need any additional details, spares or service support for this unit you may directly communicate to the manufacturer / Dealer / Indian Supplier.

High Speed Appliances, Mumbai – 400 093	Marketed by:C P Enterprises 15,Niraj Industrial Estate, Off. Mahakali Caves Road, Andheri (East), Mumbai – 400 093.
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Timer

Introduction



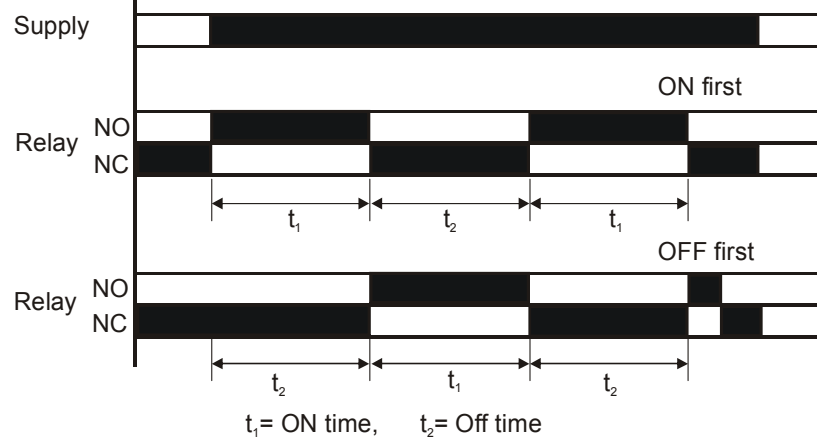
These 55 series timer are intended for general purpose electric supply on-off. Model 55C are designed for applications where electric supply on-off time unequal required.

This versatile timer series is designed for electric supply on-off time unequal set. It is perfect solution for such applications as small scale industry, industrial machinery.

Operation

The timing starts on application of power. Relay either turns on or off according to mode required (ON first/Off first). The ON time and OFF time within respective selected ranges are varied using front knobs on graduated dials. The relay status is indicated by the LED on the front bezel.

Operating mode

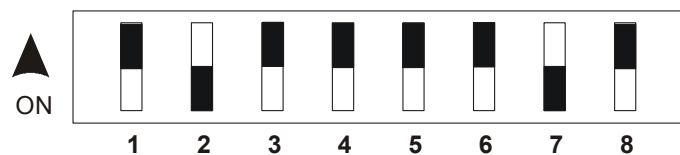


Mode and range selection

Off time				ON time			
Range	Switch settings			Range	Switch settings		
	SW1	SW2	SW3		SW6	SW7	SW8
1 sec	OFF	OFF	ON	1 sec	OFF	OFF	ON
1 min	ON	OFF	ON	1 min	ON	OFF	ON
1 hr	OFF	ON	ON	1 hr	OFF	ON	ON
10 sec	OFF	OFF	OFF	10 sec	OFF	OFF	OFF
10 min	ON	OFF	OFF	10 min	ON	OFF	OFF
10 hr	OFF	ON	OFF	10 hr	OFF	ON	OFF

Mode selection

Off time		
Mode	Switch settings	
	SW4	SW5
Off first	ON	OFF
On first	OFF	ON

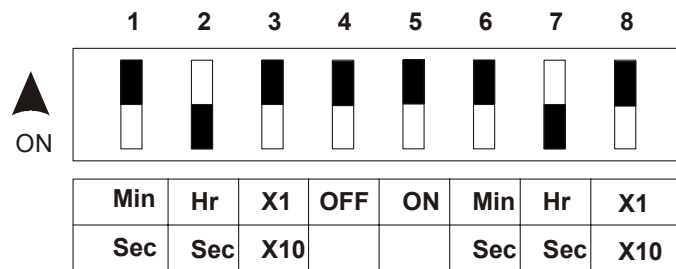


Technical specifications

Make Selectron
Model 55C – T8, cyclic

Base type	"T' screw terminal
Output contacts	2 C/O (DPDT)
Time ranges	1/10sec/min/hr for both On & Off time
Modes	Cyclic On first or Off first
Supply voltage	230V AC
Power	7.5 VA
Accuracy	Setting accuracy: +/-5% of the full scale Repeat accuracy: +/-0.5% or 50 msec
Temperature	0-50°C
Mounting	Panel mounting
Reset	reset time less than 100msec
Overall dimensions	48 x 48 x 85mm
Weight	150 gm

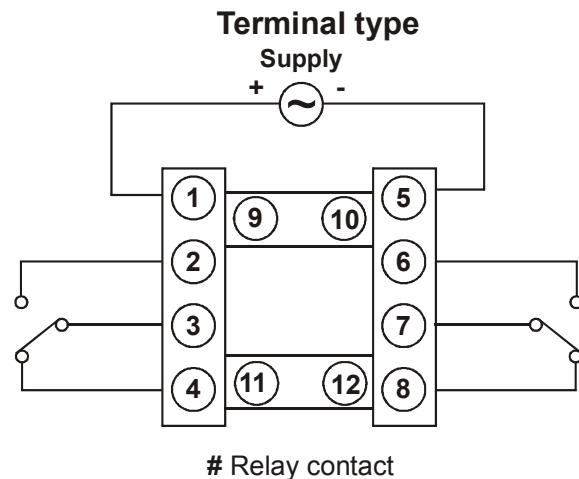
Mode Example as shown:



Off time range: 1sec
ON time range: 10min
Mode: OFF first

Terminal connection:

Terminal	Description	
1	Supply	
2	NO	#1
3	COM	#1
4	NC	#1
5	Supply	
6	NO	#2
7	COM	#2
8	NC	#2
9	--	
10	--	
11	--	
12	--	



Manufacturer's address

If you need any additional details, spares or service support for this unit you may directly communicate to the manufacturer / Dealer / Indian Supplier.

Selectron process controls Pvt. Ltd. E-121/120/113, Ansa Industrial Estate, Saki Vihar Road, Andheri, Mumbai - 400 072.	Delear: Sham traders, Kolhapur
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E-mail: selnet@bom3.vsnl.net.in Web: www.selecindia.com	
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