Department of Mechanical and Production Engineering
Ahsanullah University of Science and Technology (AUST)

IPE 3102: Measurement, Instrumentation and Control Sessional

Credit Hour: 1.5

Objective:

To get familiar with different types of measuring procedures and control equipment. Designing concepts of sampling plan, hypothesis testing.

General Instructions:

1. Attend to the lab 5 minutes prior to the scheduled time and be prepared for the experiment.
2. Students must be prepared for the experiment prior to the class.
3. Report of an experiment must be submitted in the next class.
4. Report should be submitted in the following week during the sessional time.
5. Write report on one side of an 80 gram A4 paper and follow the following format
    a) Top sheet
    b) Objective
    c) Apparatus
    d) Figure
    e) Data Sheets
    f) Sample calculation
    g) Result
    h) Graph
    i) Discussion
        i) Discuss the graphs and results
        ii) Discuss about the experimental setup if it could be improved
        iii) Discuss the different parameters that could affect the result
        iv) Discuss any assumption made
        v) Discuss any discrepancies in the experimental procedure and result
        vi) Discuss what you have learnt and the practical application of this knowledge
    j) Finally, add the data sheet with the report.

Marks Distribution:

Total Marks		
Report	Attendance and Viva	Quiz
40	10	50

Experiment no: 01

Experiment name: Goodness of Fit Test (Chi-Square Test)

THEORY:

A **statistical model** is a formalization of relationships between variables in the form of mathematical equations. A statistical model describes how one or more random variables are related to one or more random variables. The model is statistical as the variables are not deterministically but stochastically related.

Goodness of fitof a statistical model refers to how close the observed data are to those data which are predicted from a hypothesis. Measurements of goodness of fit typically summarize the discrepancy between observed values and the values expected under the model in question. Such measures can be used in statistical hypothesis testing, e.g. to test for normality of residuals, to test whether two samples are drawn from identical distributions, or whether outcome frequencies follow a specified distribution.

The chi-square test is a statistical method used to determine goodness of fit. It is used to test if a sample of data came from a population with a specific distribution.**The chi square test does not prove that a hypothesis is correct rather it evaluates to what extent the data and the hypothesis have a good fit.**

The general formula-

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

Here,

O_i= Observed Data/ Frequency in each category

E_i= Expected Data/ Frequency in each category (based on hypothesis)

If the observed frequencies are close to the corresponding expected frequencies, the χ^2 value will be small, indicating a good fit. If the observed frequencies differ considerably from the expected frequencies, the χ^2 value will be large and the fit is poor.

In other words,

- Low chi square values indicate a high probability that the observed deviations could be due to random chance alone
- High chi square values indicate a low probability that the observed deviations are due to random chance alone

APPLYING THE CHI-SQUARE TEST:

1: Propose a null hypothesis (Ho) that allows us to calculate the expected values

2: Calculate the expected values

3: Apply the chi square formula

4: Interpret the chi square value (χ^2)

5: For a level of significance (α) and degrees of freedom (ν), find the critical value (χ_α^2) from chi-square table.*

6: Then $\chi^2 > \chi_\alpha^2$ constitutes the critical region. In practice, if the chi square value results in a probability/ level of significance that is less than 0.05 (i.e.: less than 5%) it is considered statistically significant.

[The decision criterion described here should not be used unless each of the expected frequencies is at least equal to 5]

*** Degrees of Freedom:**

The concept of degrees of freedom is central to the principle of estimating statistics of populations from samples of them. "Degrees of freedom" is commonly abbreviated to df.The number of degrees of freedom associated with the chi-squared distribution used here is equal to (k-1). The number of degrees of freedom is the number of values in the final calculation of a statistic that are free to vary or, it is a measure of the number of groupings/ classes that are independent of each other. If you know the 2 of the 3 classes you can deduce the 3rd(Total number of issue – categories 1-2).

Therefore, **df = n – 1**, where, n = total number of categories

Check of normality by χ^2– test:

No. of Roller	Diameter(mm)	No. of Roller	Diameter(mm)	No. of Roller	Diameter(mm)
1	19.11	40	19.18	79	19.25
2	19.14	41	19.25	80	19.06
3	19.08	42	19.15	81	19.14
4	19.13	43	19.14	82	19.23
5	19.04	44	19.06	83	19.09
6	19.17	45	19.07	84	19.13
7	19.22	46	19.12	85	19.03
8	19.14	47	19.19	86	19.15
9	19.23	48	19.08	87	19.25
10	19.08	49	19.07	88	18.92
11	19.08	50	19.08	89	19.17
12	19.17	51	19.11	90	19.19
13	19.3	52	19.11	91	19.14
14	19.14	53	19.12	92	19.19
15	18.94	54	19.13	93	19.12
16	19.19	55	19.11	94	19.19
17	19.15	56	19.01	95	19.15
18	18.93	57	19.24	96	19.07
19	19.15	58	19.12	97	19.04
20	19.31	59	19.21	98	19.19
21	19.15	60	19.2	99	18.98
22	19.11	61	19.18	100	19.14

23	19.21	62	19.18	101	19.15
24	19.11	63	19.13	102	19.09
25	19.17	64	19.11	103	19.19
26	19.15	65	19.09	104	19.1
27	19.1	66	19.14	105	19.16
28	19.11	67	19.24	106	19.25
29	18.89	68	19.14	107	19.12
30	19.21	69	19.14	108	19.13
31	19.14	70	19.15	109	19.16
32	19.12	71	19.08	110	19.16
33	19.14	72	19.11	111	19.01
34	19.18	73	19.07	112	18.93
35	19.22	74	19.18	113	19.11
36	19.07	75	19.14	114	19.09
37	19.14	76	19.15	115	19.04
38	19.06	77	19.12	116	18.94
39	19.08	78	19.16	117	19.06

No. of Roller	Diameter(mm)	No. of Roller	Diameter(mm)	No. of Roller	Diameter(mm)
118	19.06	129	19.2	140	19.01
119	19.12	130	19.15	141	19.05

120	19.01	131	18.98	142	18.85
121	19.11	132	19.15	143	18.99
122	19.08	133	19.12	144	19.2
123	19.03	134	19.12	145	19.35
124	19.12	135	19.06	146	19.02
125	19.09	136	19.16	147	19.04
126	19.02	137	19.29	148	19.11
127	19	138	19.11	149	19.1
128	19.19	139	19.09	150	19.15

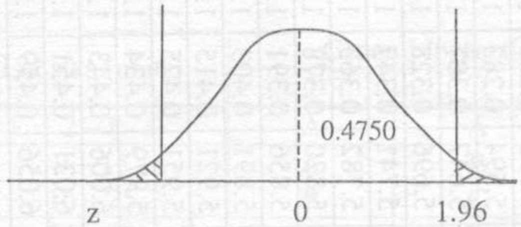
STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
0.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
0.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
0.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
0.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
0.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
0.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
0.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
0.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
0.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97778	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99889	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989
3.7	.99989	.99990	.99990	.99990	.99991	.99991	.99992	.99992	.99992	.99992
3.8	.99993	.99993	.99993	.99994	.99994	.99994	.99994	.99995	.99995	.99995
3.9	.99995	.99995	.99996	.99996	.99996	.99996	.99996	.99996	.99997	.99997

STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
-3.9	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00004	.00003	.00003
-3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.00005
-3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00008	.00008	.00008	.00008
-3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.00011
-3.5	.00023	.00022	.00022	.00021	.00020	.00019	.00019	.00018	.00017	.00017
-3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.00024
-3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.00035
-3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.00050
-3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.00071
-3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00104	.00100
-2.9	.00187	.00181	.00175	.00169	.00164	.00159	.00154	.00149	.00144	.00139
-2.8	.00256	.00248	.00240	.00233	.00226	.00219	.00212	.00205	.00199	.00193
-2.7	.00347	.00336	.00326	.00317	.00307	.00298	.00289	.00280	.00272	.00264
-2.6	.00466	.00453	.00440	.00427	.00415	.00402	.00391	.00379	.00368	.00357
-2.5	.00621	.00604	.00587	.00570	.00554	.00539	.00523	.00508	.00494	.00480
-2.4	.00820	.00798	.00776	.00755	.00734	.00714	.00695	.00676	.00657	.00639
-2.3	.01072	.01044	.01017	.00990	.00964	.00939	.00914	.00889	.00866	.00842
-2.2	.01390	.01355	.01321	.01287	.01255	.01222	.01191	.01160	.01130	.01101
-2.1	.01786	.01743	.01700	.01659	.01618	.01578	.01539	.01500	.01463	.01426
-2.0	.02275	.02222	.02169	.02118	.02068	.02018	.01970	.01923	.01876	.01831
-1.9	.02872	.02807	.02743	.02680	.02619	.02559	.02500	.02442	.02385	.02330
-1.8	.03593	.03515	.03438	.03362	.03288	.03216	.03144	.03074	.03005	.02938
-1.7	.04457	.04363	.04272	.04182	.04093	.04006	.03920	.03836	.03754	.03673
-1.6	.05480	.05370	.05262	.05155	.05050	.04947	.04846	.04746	.04648	.04551
-1.5	.06681	.06552	.06426	.06301	.06178	.06057	.05938	.05821	.05705	.05592
-1.4	.08076	.07927	.07780	.07636	.07493	.07353	.07215	.07078	.06944	.06811
-1.3	.09680	.09510	.09342	.09176	.09012	.08851	.08691	.08534	.08379	.08226
-1.2	.11507	.11314	.11123	.10935	.10749	.10565	.10383	.10204	.10027	.09853
-1.1	.13567	.13350	.13136	.12924	.12714	.12507	.12302	.12100	.11900	.11702
-1.0	.15866	.15625	.15386	.15151	.14917	.14686	.14457	.14231	.14007	.13786
-0.9	.18406	.18141	.17879	.17619	.17361	.17106	.16853	.16602	.16354	.16109
-0.8	.21186	.20897	.20611	.20327	.20045	.19766	.19489	.19215	.18943	.18673
-0.7	.24196	.23885	.23576	.23270	.22965	.22663	.22363	.22065	.21770	.21476
-0.6	.27425	.27093	.26763	.26435	.26109	.25785	.25463	.25143	.24825	.24510
-0.5	.30854	.30503	.30153	.29806	.29460	.29116	.28774	.28434	.28096	.27760
-0.4	.34458	.34090	.33724	.33360	.32997	.32636	.32276	.31918	.31561	.31207
-0.3	.38209	.37828	.37448	.37070	.36693	.36317	.35942	.35569	.35197	.34827
-0.2	.42074	.41683	.41294	.40905	.40517	.40129	.39743	.39358	.38974	.38591
-0.1	.46017	.45620	.45224	.44828	.44433	.44038	.43644	.43251	.42858	.42465
-0.0	.50000	.49601	.49202	.48803	.48405	.48006	.47608	.47210	.46812	.46414

Table A. Standard Normal Distribution Values (Areas under the normal curve).



z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2517	0.2549
0.7	0.2580	0.2611	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4979	0.4980	0.4981
2.9	0.4981	0.4982	0.4982	0.4983	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4987	0.4987	0.4987	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990	0.4990

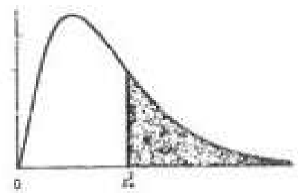


Table A.5 Critical Values of the Chi-Squared Distribution

	α									
v	0.995	0.99	0.98	0.975	0.95	0.90	0.80	0.75	0.70	0.50
1	0.0^4393	0.0^3157	0.0^3628	0.0^3982	0.00393	0.0158	0.0642	0.102	0.148	0.455
2	0.0100	0.0201	0.0404	0.0506	0.103	0.211	0.446	0.575	0.713	1.386
3	0.0717	0.115	0.185	0.216	0.352	0.584	1.005	1.213	1.424	2.366
4	0.207	0.297	0.429	0.484	0.711	1.064	1.649	1.923	2.195	3.357
5	0.412	0.554	0.752	0.831	1.145	1.610	2.343	2.675	3.000	4.351
6	0.676	0.872	1.134	1.237	1.635	2.204	3.070	3.455	3.828	5.348
7	0.989	1.239	1.564	1.690	2.167	2.833	3.822	4.255	4.671	6.346
8	1.344	1.647	2.032	2.180	2.733	3.490	4.594	5.071	5.527	7.344
9	1.735	2.088	2.532	2.700	3.325	4.168	5.380	5.899	6.393	8.343
10	2.156	2.558	3.059	3.247	3.940	4.865	6.179	6.737	7.267	9.342
11	2.603	3.053	3.609	3.816	4.575	5.578	6.989	7.584	8.148	10.341
12	3.074	3.571	4.178	4.404	5.226	6.304	7.807	8.438	9.034	11.340
13	3.565	4.107	4.765	5.009	5.892	7.041	8.634	9.299	9.926	12.340
14	4.075	4.660	5.368	5.629	6.571	7.790	9.467	10.165	10.821	13.339
15	4.601	5.229	5.985	6.262	7.261	8.547	10.307	11.037	11.721	14.339
16	5.142	5.812	6.614	6.908	7.962	9.312	11.152	11.912	12.624	15.338
17	5.697	6.408	7.255	7.564	8.672	10.085	12.002	12.792	13.531	16.338
18	6.265	7.015	7.906	8.231	9.390	10.865	12.857	13.675	14.440	17.338
19	6.844	7.633	8.567	8.907	10.117	11.651	13.716	14.562	15.352	18.338
20	7.434	8.260	9.237	9.591	10.851	12.443	14.578	15.452	16.266	19.337
21	8.034	8.897	9.915	10.283	11.591	13.240	15.445	16.344	17.182	20.337
22	8.643	9.542	10.600	10.982	12.338	14.041	16.314	17.240	18.101	21.337
23	9.260	10.196	11.293	11.689	13.091	14.848	17.187	18.137	19.021	22.337
24	9.886	10.856	11.992	12.401	13.848	15.659	18.062	19.037	19.943	23.337
25	10.520	11.524	12.697	13.120	14.611	16.473	18.940	19.939	20.867	24.337
26	11.160	12.198	13.409	13.844	15.379	17.292	19.820	20.843	21.792	25.336
27	11.808	12.878	14.125	14.573	16.151	18.114	20.703	21.749	22.719	26.336
28	12.461	13.565	14.847	15.308	16.928	18.939	21.588	22.657	23.647	27.336
29	13.121	14.256	15.574	16.047	17.708	19.768	22.475	23.567	24.577	28.336
30	13.787	14.953	16.306	16.791	18.493	20.599	23.364	24.478	25.508	29.336
40	20.707	22.164	23.838	24.433	26.509	29.051	32.345	33.66	34.872	39.335
50	27.991	29.707	31.664	32.357	34.764	37.689	41.449	42.942	44.313	49.335
60	35.534	37.485	39.699	40.482	43.188	46.459	50.641	52.294	53.809	59.335

Table A.5 (continued) Critical Values of the Chi-Squared Distribution

v	α = 0.30	0.25	0.20	0.10	0.05	0.025	0.02	0.01	0.005	0.001
1	1.074	1.323	1.642	2.706	3.841	5.024	5.412	6.635	7.879	10.827
2	2.408	2.773	3.219	4.605	5.991	7.378	7.824	9.210	10.597	13.815
3	3.665	4.108	4.642	6.251	7.815	9.348	9.837	11.345	12.838	16.266
4	4.878	5.385	5.989	7.779	9.488	11.143	11.668	13.277	14.860	18.466
5	6.064	6.626	7.289	9.236	11.070	12.832	13.388	15.086	16.750	20.515
6	7.231	7.841	8.558	10.645	12.592	14.449	15.033	16.812	18.548	22.457
7	8.383	9.037	9.803	12.017	14.067	16.013	16.622	18.475	20.278	24.321
8	9.524	10.219	11.030	13.362	15.507	17.535	18.168	20.090	21.955	26.124
9	10.656	11.389	12.242	14.684	16.919	19.023	19.679	21.666	23.589	27.877
10	11.781	12.549	13.442	15.987	18.307	20.483	21.161	23.209	25.188	29.588
11	12.899	13.701	14.631	17.275	19.675	21.920	22.618	24.725	26.757	31.264
12	14.011	14.845	15.812	18.549	21.026	23.337	24.054	26.217	28.300	32.909
13	15.119	15.984	16.985	19.812	22.362	24.736	25.471	27.688	29.819	34.527
14	16.222	17.117	18.151	21.064	23.685	26.119	26.873	29.141	31.319	36.124
15	17.322	18.245	19.311	22.307	24.996	27.488	28.259	30.578	32.801	37.698
16	18.418	19.369	20.465	23.542	26.296	28.845	29.633	32.000	34.267	39.252
17	19.511	20.489	21.615	24.769	27.587	30.191	30.995	33.409	35.718	40.791
18	20.601	21.605	22.760	25.989	28.869	31.526	32.346	34.805	37.156	42.312
19	21.689	22.718	23.900	27.204	30.144	32.852	33.687	36.191	38.582	43.819
20	22.775	23.828	25.038	28.412	31.410	34.170	35.020	37.566	39.997	45.314
21	23.858	24.935	26.171	29.615	32.671	35.479	36.343	38.932	41.401	46.796
22	24.939	26.039	27.301	30.813	33.924	36.781	37.659	40.289	42.796	48.268
23	26.018	27.141	28.429	32.007	35.172	38.076	38.968	41.638	44.181	49.728
24	27.096	28.241	29.553	33.196	36.415	39.364	40.270	42.980	45.558	51.179
25	28.172	29.339	30.675	34.382	37.652	40.646	41.566	44.314	46.928	52.619
26	29.246	30.435	31.795	35.563	38.885	41.923	42.856	45.642	48.290	54.051
27	30.319	31.528	32.912	36.741	40.113	43.195	44.140	46.963	49.645	55.475
28	31.391	32.620	34.027	37.916	41.337	44.461	45.419	48.278	50.994	56.892
29	32.461	33.711	35.139	39.087	42.557	45.722	46.693	49.588	52.335	58.301
30	33.530	34.800	36.250	40.256	43.773	46.979	47.962	50.892	53.672	59.702
40	44.165	45.616	47.269	51.805	55.758	59.342	60.436	63.691	66.766	73.403
50	54.723	56.334	58.164	63.167	67.505	71.420	72.613	76.154	79.490	86.660
60	65.226	66.981	68.972	74.397	79.082	83.298	84.58	88.379	91.952	99.608

Experiment no: 02

Experiment name: Applying Two Ball& Four Ball Method to Determine Diameter of a Recessed Hole

<u>THEORY:</u>

Diameter of a hollow cylinder can be measured using a Vernier Caliper. But, this method might not work well with a recessed hole. “Two ball” method can be applied to obtain the diameter of a recessed hole. Though, higher accuracy cannot be attained with this method, this is an optimal solution to know about the diameter of a recessed hole approximately.

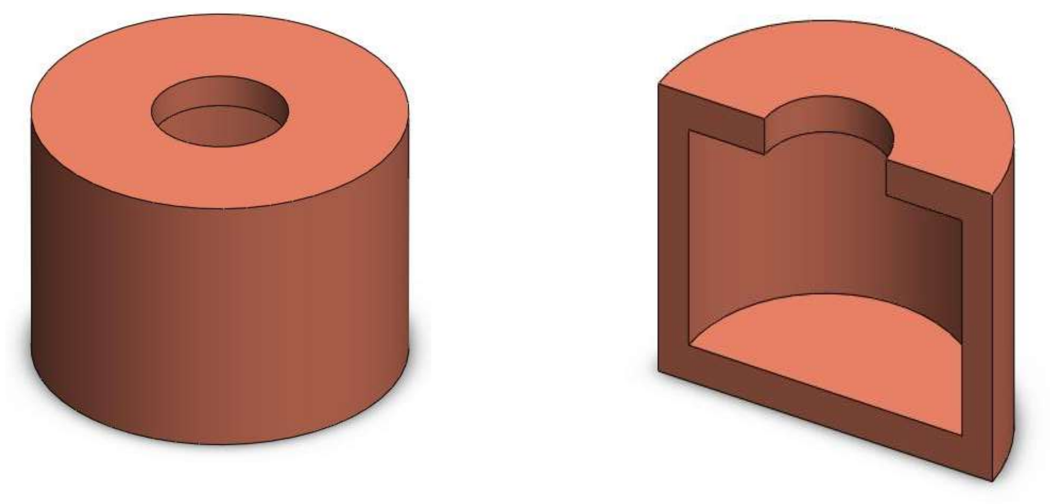


Fig. 2.1: Recessed hole (a) Isometric View (b) Section or, Cutaway view of the hole

CALCULATION:

$$C^2 = \left(\frac{d_1 + d_2}{2}\right)^2 - \left(H_2 - H_1 + \frac{d_2 - d_1}{2}\right)^2$$

$$D = C + \frac{d_1+d_2}{2}$$

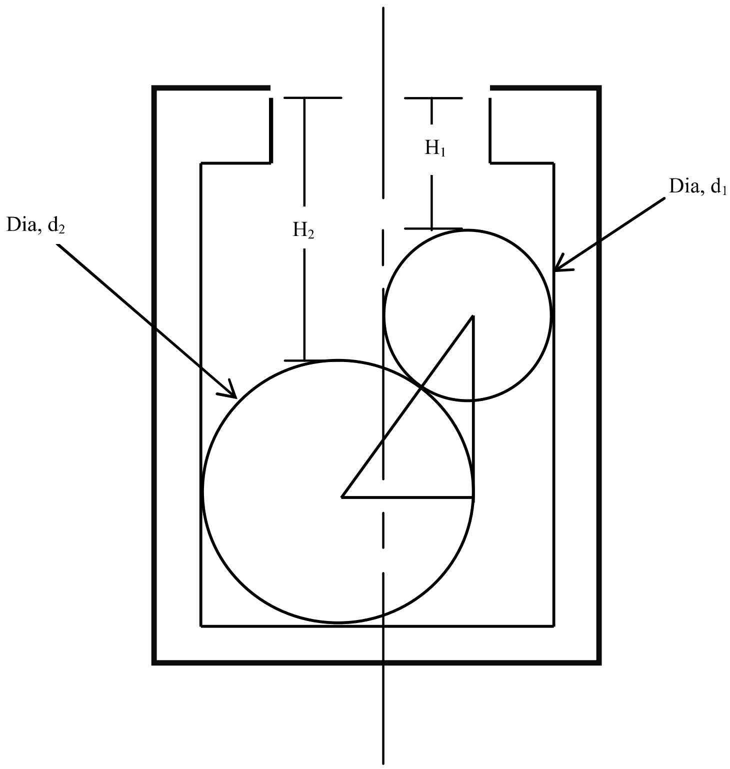


Fig. 2.2: Measurement of Diameter of Hole by Two Balls

Ahsanullah University of Science and Technology

Department of Mechanical and Production Engineering

IPE 3102

Datasheet

Experiment 02

Name of the Student:
Student ID:

Diameter of ball 1, d_1 = mm
Diameter of ball 2, d_2 = mm

Height recorded from the top to ball 2, H_2 = mm
Height recorded from the top to ball 1, H_1 = mm

Result:
Diameter of the recessed hole, D = mm

Signature of Course Teacher

Experiment no: 03

Experiment name: Design and Implementation of a Lot-By-Lot Acceptance Sampling Plan

THEORY:

Sampling is a quality assurance tool. It is based on the idea that a random selection of sample from a homogenous lot or, batch of goods represents the quality of the lot. It is obvious that sampling involves risks but apart from the necessity of acceptance sampling as in the case of destructive testing, advantages of sampling are significant. It is also to be remembered that the purpose of sampling is to guide the course of action, not to estimate the lot quality and also the quality of the goods being inspected is not improved. Further, acceptance sampling is not an attempt to **'control'**the quality but to **'assure'** the quality.

As mentioned above, acceptance Sampling is a form of inspection which is used to determine whether or not products or, goods are coherent with a preset standard of quality. Acceptance Sampling is applied to lots or batches of products or, goods before or after a process to judge conformance to predetermined standards. The lot is either accepted or, rejected depending on the quality standard of the samples taken. It can be applied at the input stage of a production process to prevent raw materials that don't meet the standards from entering into the process. Applying sampling plan at the initial stage of production saves reworking time and money. Acceptance sampling is also applied at the output stage of a production process which reduces the risk of bad quality being passed on from the process to a consumer.

Sampling Plans specify the lot size, sample size, number of samples and acceptance/rejection criteria. Most generally used sampling scheme is single sampling plan. Among others there are double sampling plans, multiple sampling plan and sequential sampling plans.

Single Sampling Plan:
A single sampling plan is a lot sentencing procedure in which one sample of 'n' units is selected randomly from a lot of 'N' units. Each item in the sample is examined and classified as good/defective. If the number of defective exceeds a specified rejection number (k) the whole lot is rejected; otherwise the whole lot is accepted.
Here,

N = Lot size
n = Sample size
k = Acceptance number

If 'k' or less non-conforming units are found in the sample, the lot is **accepted**, else it is **rejected**.

The real problem in most acceptance sampling is to design a satisfactory acceptance sampling system or more commonly, to select such a system from a number of possible systems already developed. To judge the suitability of any proposed acceptance sampling system in a particular case, it is desirable to have an understanding of the strategy and tactics built into the various available types of systems.

Based on manufacturer's product quality, data-type e.g. variables and attributes, can also classify sampling plan. Variables, of course are quality characteristics that are measured on a numerical scale. Attributes are quality characteristics that are expressed on a "go, no-go" basis. Present day industrial practice of acceptance sampling is by attributes. But, the growth of knowledge of statistical quality control techniques has led to a considerable increase in the industrial use of acceptance sampling by variables. Acceptance sampling by variables is often preferable, though costly, to acceptance sampling by attributes, particularly for those quality characteristics that are sources of troubles. The great advantage of the use of acceptance sampling by variables is that more information is obtained about the quality characteristics in question. In this experiment, an acceptance sampling plan for variables will be designed and implemented.

Nomenclature:

α = Producer's risk

β = Consumer's risk

P_1 = Lot fraction defective for which probability (Acceptance) $\geq 1 - \alpha$

P_2 = Lot fraction defective for which probability (Acceptance) $\leq \beta$

LSL = Lower specification limit

USL = Upper specification limit

n = Sample size

k = Critical value

$\bar{X}$ = Sample mean

$\hat{P}_{LSL}$ = Fraction defective estimates corresponding to LSL

$\hat{P}_{USL}$ = Fraction defective estimates corresponding to USL

M = Allowable fraction defective

$$S = \sqrt{\frac{\sum(X - \bar{X})^2}{n-1}}$$

$$Z(LSL) = \frac{\bar{X} - LSL}{s}$$

$$Z(USL) = \frac{USL - \bar{X}}{s}$$

Procedure:

The nomograph shown in fig. 3.1 is used to find the required sample size n and the critical value k to meet a set of given conditions P_1,P_2, $1 - \alpha$, β for both the σ known and σ unknown cases. The greater the uncertainty in the case where the standard deviation is unknown requires a larger sample size than does σ known case but the same value of k is used.

After determining n and k from the nomograph, the diameters of the balls supplied is measured and $\bar{X}$ and S is calculated. From given LSL and USL values Z (LSL) and Z (USL) is calculated. From fig. 3.2 the value of M is determined. $\hat{P}_{LSL}$ and $\hat{P}_{USL}$ can be determined from fig 3.3.

If $\hat{P}_{LSL} + \hat{P}_{USL} \leq M$,the lot will be accepted, otherwise it will be rejected.

Assignment:

The density of a plastic used in a packet calculator to be at least 0.70 gm/cm^3. The parts are supplied in large lots and a variable sampling plan is to be used to sentence the lots. It is desired to have $\alpha = 0.1$, $\beta = 0.05$, $P_1 = 0.02$ and $P_2 = 0.1$. The variability of the manufacturing process is unknown but will be estimated by the sample standard deviation.

a) Find an appropriate variable sampling plan.
b) Suppose that a sample of appropriate size was taken, and $\bar{X} = 0.73$and $S = 1.05\times10^{-2}$ Should the lot be accepted or rejected.

Question:

a) Explain: Acceptance sampling is not an attempt to **'control'** the quality but to **'assure'** the quality.
b) Why $P_1 \geq 1 - \alpha$and$P_2 \leq \beta$ explain?
c) What are the advantages of lot by lot acceptance sampling?
d) Write the difference between attributes and variables type acceptance sampling plan?

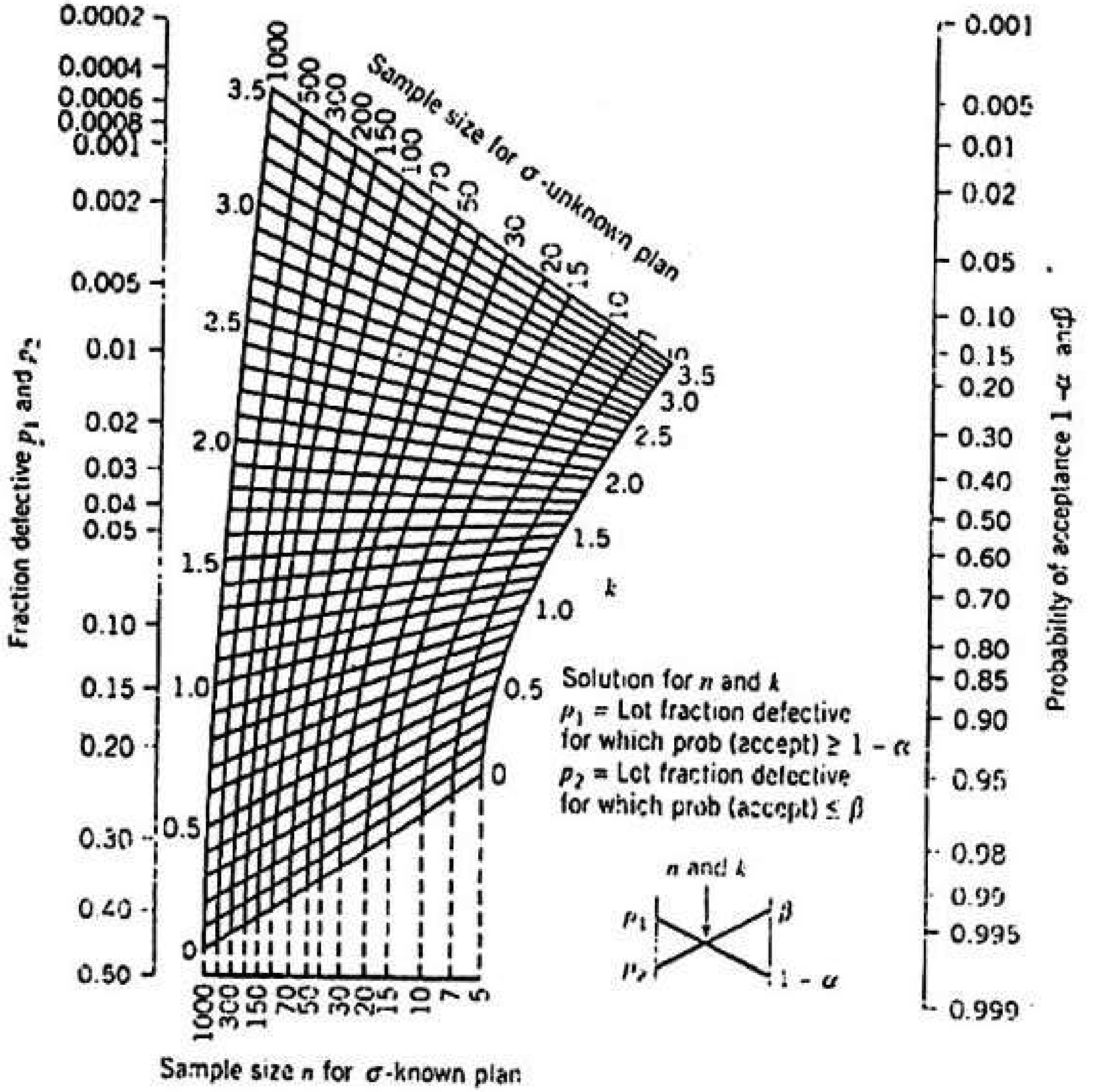
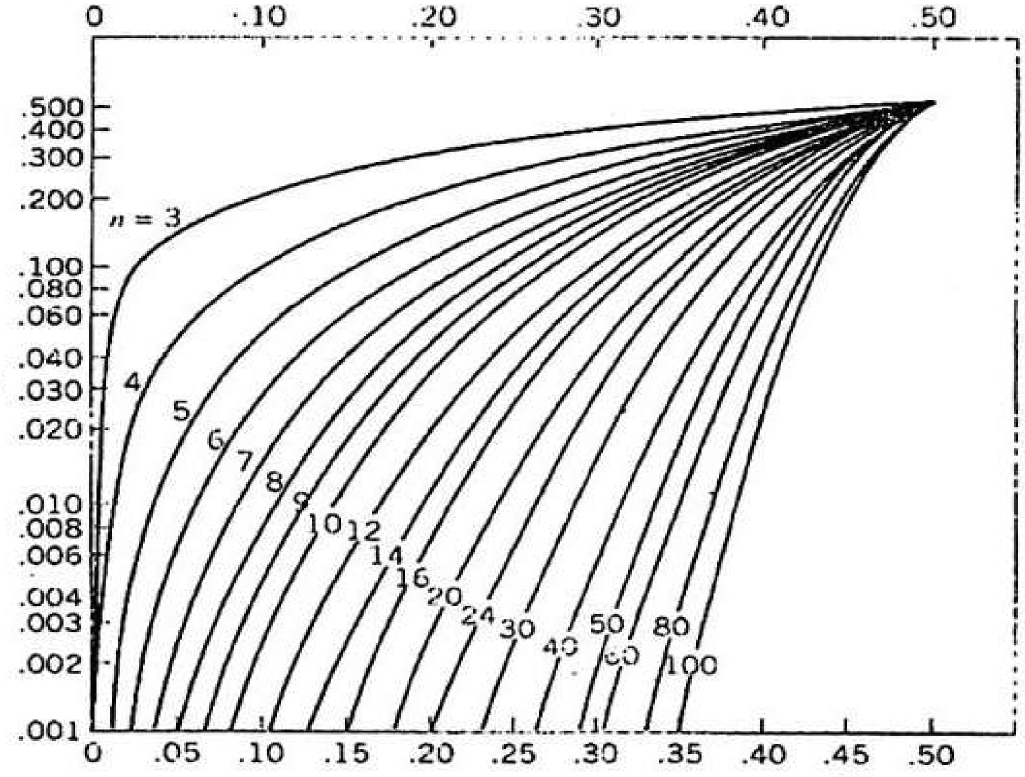


Figure 3.1 : Nomograph for Designing Variables Sampling Plan



For standard deviation plans take abscissa = $\frac{1 - k\sqrt{n}/(n-1)}{2}$

Figure 3.2 Chart for determining maximum allowable fraction defective M

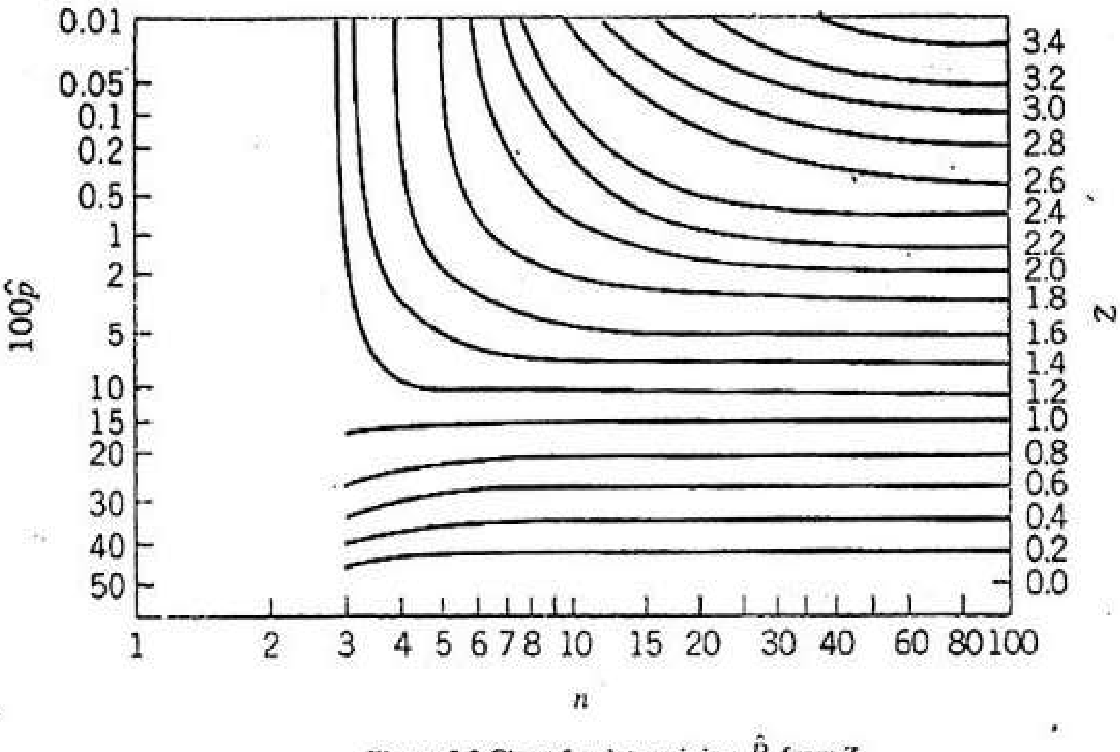


Figure 3.3 Chart for determining $\hat{P}$ from Z

Experiment No: 04

Experiment Name: Vernier Bevel Protractor

Objectives:

- Learn and understand different parts of Vernier Bevel Protractor
- Know the use and working principle of Vernier Bevel Protractor
- Understand the use of Vernier Bevel Protractor

Vernier Bevel Protractor:

It is also called universal bevel protractor. It is one of the simplest instruments for angular measurement. It is a direct type of angular measuring instrument. The range of this instrument is 0 to 360 degrees i.e. it can measure angles up to 360 degrees which any other angular measuring instrument cannot measure. It also has two arms (fixed blade and adjustable blade), which can be set along the faces and a circular scale to indicate the angle between them. Workpiece is set in between these two arms (two blades, fixed blade and adjustable blade), and the difference of two scale (main scale and Vernier scale) gives accurate measurement. Main parts of bevel protractor are-

- Fixed base blade and a circular body is attached to it
- Adjustable blade
- Blade clamp
- Scale magnifier lens
- Acute angle attachment

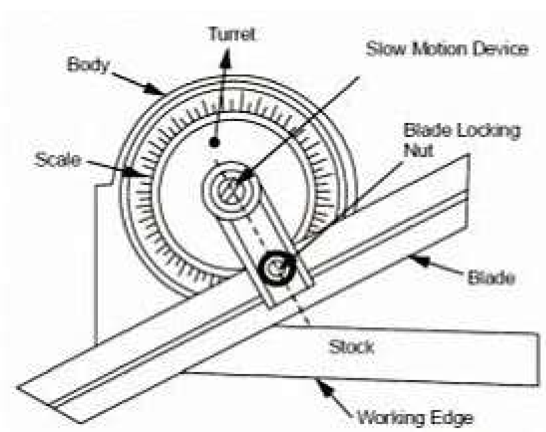


Fig 4.1: Vernier Bevel Protractor

Note that, magnifying lens has been provided for easy reading of the instrument. Main scale is circular and is graduated in degrees on the circular body. Main scale graduations are all around the circular body which is attached to fixed base blade. Fixed base blade also called as stock is attached to circular body of bevel protractor as shown in figure. Once the reading is fixed, blade clamp fixes the reading. Blades are about 150 mm long or 300 mm long, 13 mm thick. Its ends are beveled at 45 degrees and 60 degrees. Vernier scale is also marked on turret which can rotate all over the fixed body. Adjustable can pass through the slot provided in turret. So as the turret rotates, adjustable blade also rotates full 360 degrees. There are 12 graduations of Vernier scale starting from 0 to 60 degrees on both sides of zero of Vernier scale.

How to read Vernier scale:

- If the indicator on the Vernier is corresponding to that on the main scale, then directly read on the main scale.
- If the zero indicator on the Vernier indicates rightward of the zero indicator on the main scale, read on the right side of the Vernier. Example of fig 3.2 shows that 15 degree on the right side of the Vernier is directly in correspondence with the main scale so the reading is $12^{o}\ 15'$.
- If the zero indicator of the Vernier indicates on the left side of the zero indicators on the main scale, read on the left side of the Vernier.

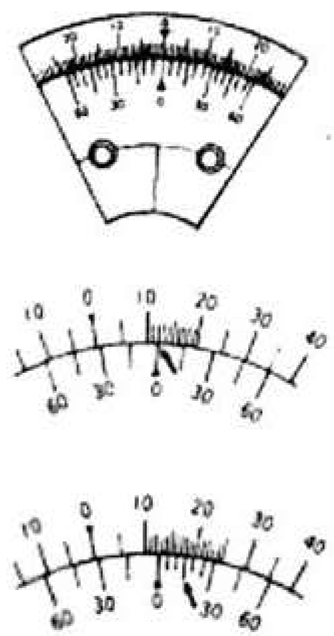


Fig 4.2: How to read Vernier scale

Least count of Vernier Bevel Protractor:

Least count of Vernier Bevel Protractor $= \frac{\text{smallest division on the main scale}}{\text{Total no of division on the Vernier scale}}$

$$= 1^{o} \text{ (equal to } 60'\text{) i.e.} \frac{60}{12}$$

= 5 minutes (written as 5′)

Application of Vernier Bevel Protractor:

The bevel protractor can be used in the following applications-

- For checking V-block
- For measuring acute angle

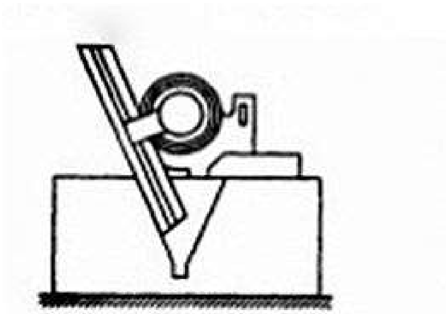


Fig 4.3: Checking V-block

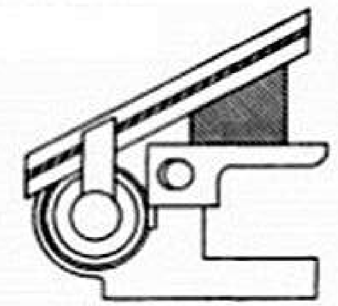


Fig 4.4: Measuring acute angle

Assignment:

Find the difference of the angle in between the dial of hour and the dial of minute when your clock indicates-

a) 3:30
b) 11:59
c) 12:00

Experiment 1

Basics of Programmable Logic Controller (PLC)

Objective: To learn basics of Programmable logic controller, logic diagrams, Boolean algebra and ladder logic diagrams.

<u>What is PLC:</u>

- Programmable Logic Controller or PLC's are the solid state member of computer family.
- It is a special form of microprocessor-based controller that uses programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting, and arithmetic in order to control machines and processes.
- It uses integrated circuit instead of electromechanical devices to implement control.
- A PLC monitors inputs, makes decisions based on its program, and controls outputs to automate a process or machine.
- PLCs are similar to computers, but whereas computers are optimized for calculation and display tasks, PLCs are optimized for control tasks and the industrial environment.

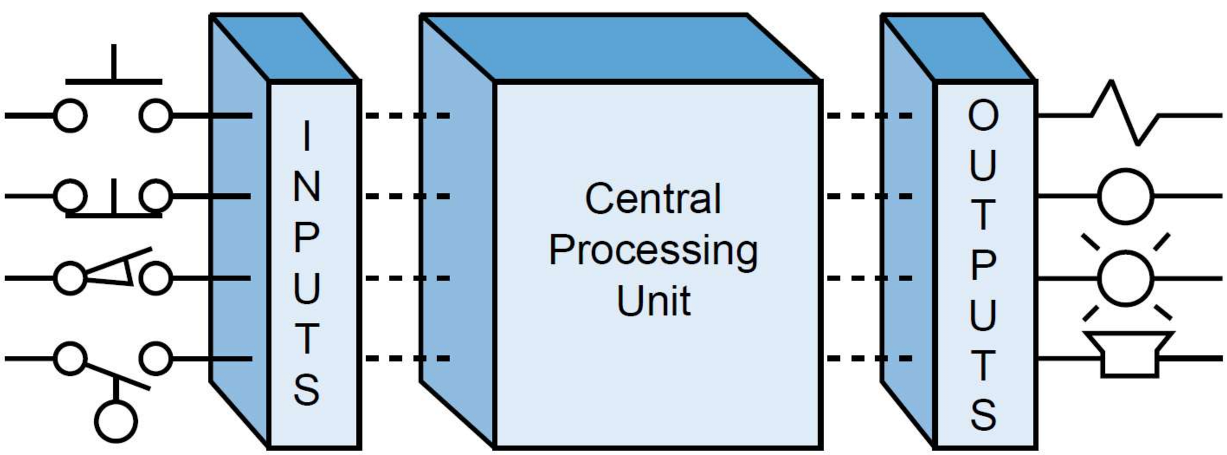


Figure: PLC schematic

Features of PLC:

- Rugged design; suitable for harsh industrial environments against high temperature variations, dust and vibrations.

- Industry standard I/O interfaces; capable of communicating with other PLCs, computers and intelligent devices.
- Industry standard programming languages; easily learned and understood. Programming is primarily concerned with logic, timing, counting and switching operations.
- Field programmable.
- Reduces hard wiring and wiring cost.
- Monitoring, error checking and diagnostics capability.
- Competitive in both cost and space requirements.

Applications of PLC:

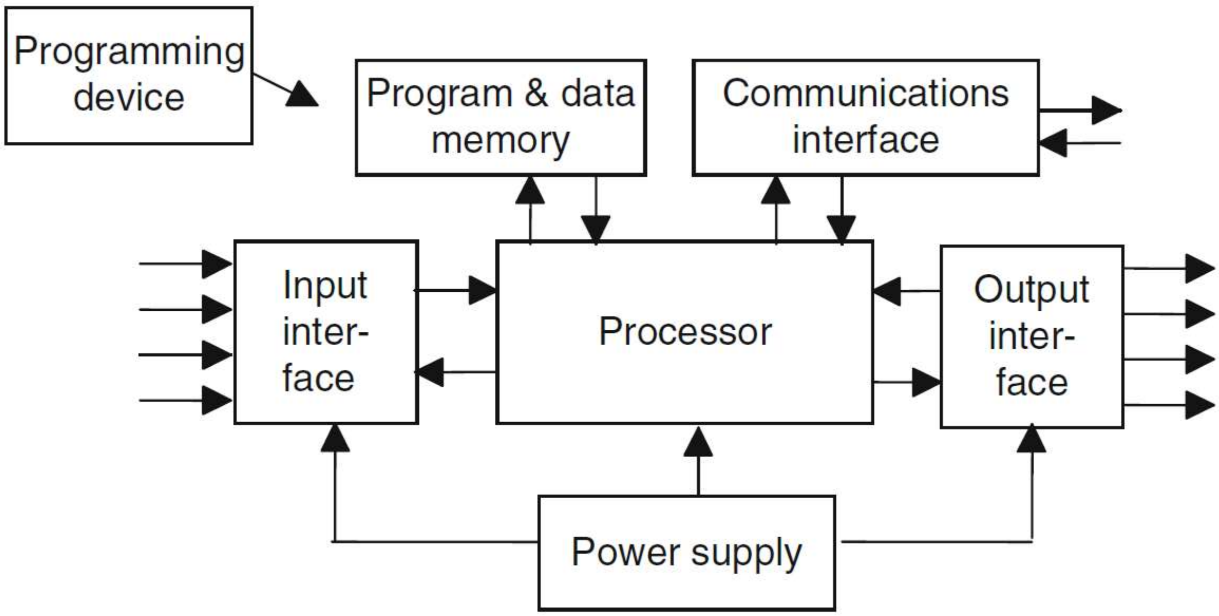
- Manufacturing/Machining
    - Assembly machines
    - Boring
    - Cranes
    - Energy demand
    - Grinding
    - Injection/blow molding
    - Material conveyors
    - Metal casting
    - Milling
    - Painting
    - Plating
    - Tracer lathe
    - Welding
- Metals
    - Blast furnace control
    - Continuous casting
    - Rolling mills
    - Soaking pit
- Mining
    - Bulk material conveyors
    - Loading/unloading
    - Ore processing
    - Water/waste management
- Lumber/Pulp/Paper
    - Batch digesters
    - Chip handling

Major Components: PLC consists of five major sections:

1. Power Supply
2. Memory
3. Central Processing Unit (CPU)
4. I/O Interface
5. Programming Section

Principles of Operation:

- An **input** accepts a variety of digital or analog signals from various field devices or ***sensors*** and converts them into a logic signal that can be used by the CPU.
- These field devices may be discrete or analog input devices, such as,
  - Limit switches
  - Pressure transducers
  - Push buttons
  - Motor starters
  - Solenoids, etc.
- The **CPU** makes decisions and executes control instructions based on program instructions in memory.
- During its operation, the CPU completes three processes:
  - It *reads*, or accepts, the input data from the field devices via the input interfaces
  - It *executes*, or performs, the control program stored in the memory system, and
  - It *writes*, or updates, the output devices via the output interfaces.
- This process of sequentially reading the inputs, executing the program in memory and updating the outputs is known as ***scanning***.



- **Output** modules convert control instructions from the CPU into a digital or analog signal that can be used to control various field devices or ***actuators***.
- A **programming devices (programmer)**, usually a personal computer or a manufacturer's miniprogrammer unit, is required to enter the control program or instructions into memory.
- These instructions determine what the PLC will do for a specific input.
- An operator interface device allows process information to be displayed and new control parameters to be entered.

The system power supply provides all the voltages required for the proper operation of the various central processing.

PLC Programming Languages:

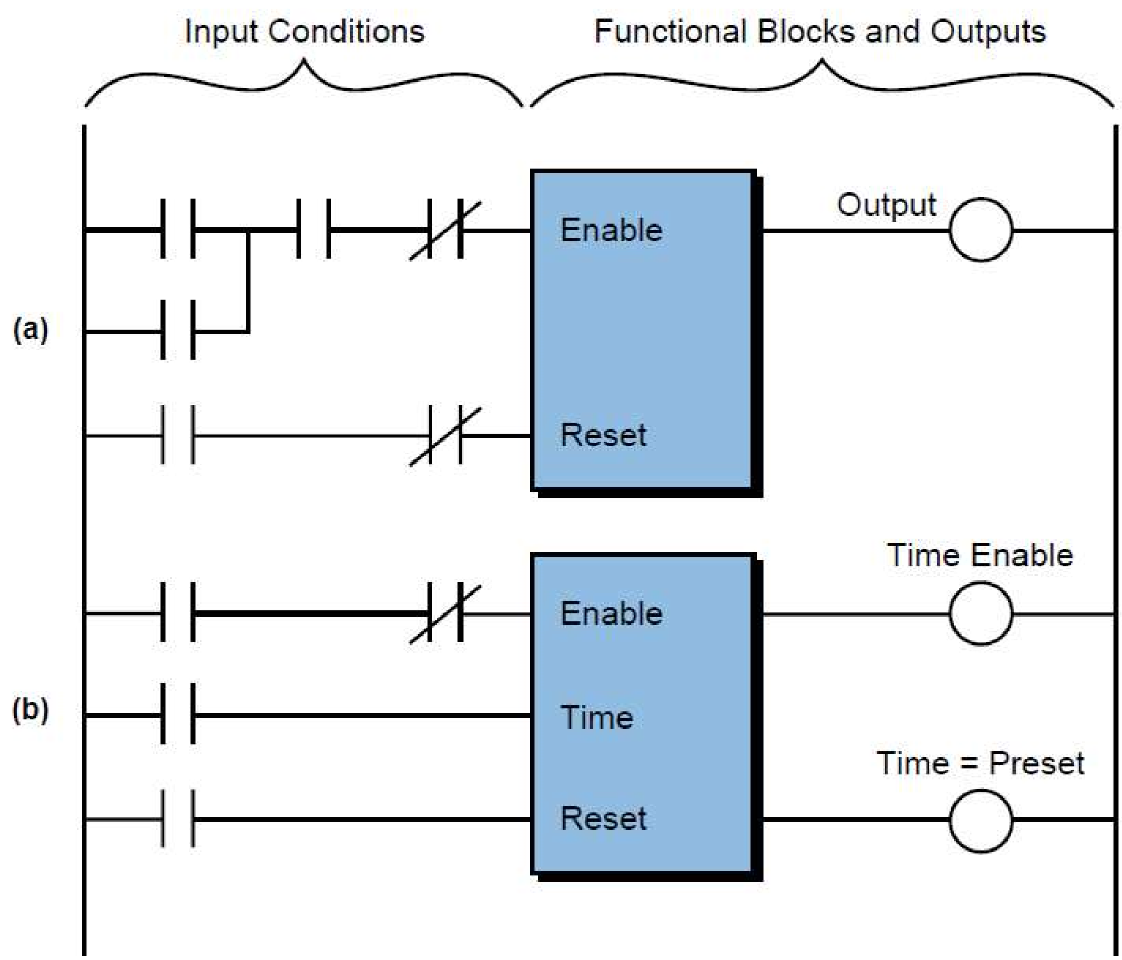
- There are five PLC programming languages;
    1. **Ladder Diagram(LAD):** Graphic language derived from circuit diagram of directly wired relay controls
    2. **Function Block Diagram (FBD)** :Functions & functions block are represented graphically and interconnected into networks.
    3. **Instruction List (IL):** Textual assembler-type language consisting of an operator and an operand.
    4. **Structured Text (ST)**: High level language based on Pascal.
    5. **Sequential Function Chart (SFC):** A language resource for the structuring of sequence-oriented control programs.

Ladder Diagram:

- Ladder diagram is type of graphic language for automatic control systems it had been used for a long period since World War II.
- The use of ladder programming involves writing a program in a manner to drawing a switching circuit.
- Originally there are only few basic elements available such as Normally Open or contact, Normally Closed or contact, output coil, timers and counters.

Ladder Programming Convetions:

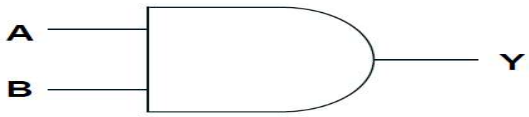
- When a ladder diagram contains a functional block, contact instructions are used to represent the input conditions that drive the block's logic.
- A functional block can have one or more enable inputs that control its operation. In addition, it can have one or more output coils, which signify the status of the function being performed.



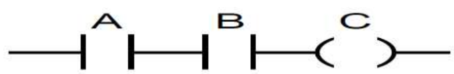
Ladder Programming Convetions

Logical Functions:

AND Gate

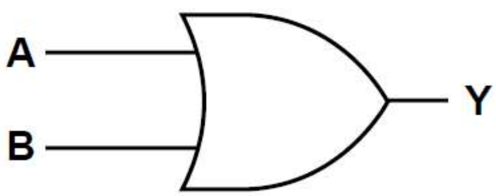


AND Truth Table		
Inputs		Output
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1



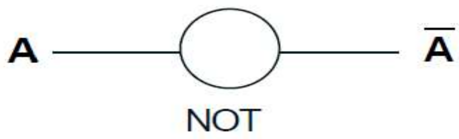
AND
Equivalent Circuit

OR Gate:



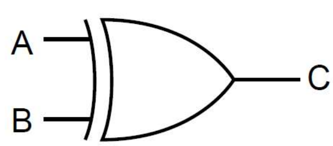
OR Truth Table		
Inputs		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

NOT Gate:



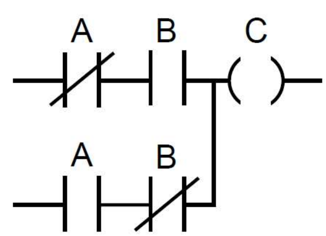
NOT Truth Table	
Input	Output
A	$\overline{A}$
0	1
1	0

XOR gate:



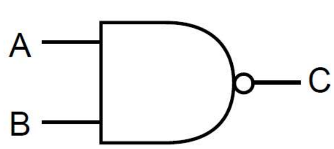
Exclusive-OR
Gate

A	B	C
0	0	0
0	1	1
1	0	1
1	1	0



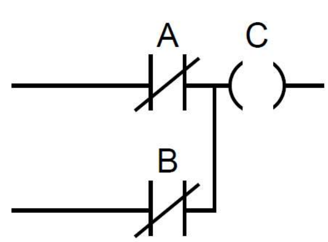
Exclusive-OR
Equivalent Circuit

NAND gate:



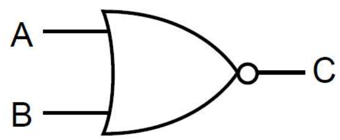
NAND
Gate

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0



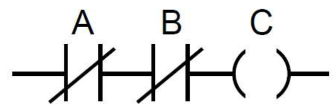
NAND
Equivalent Circuit

NOR GATE:



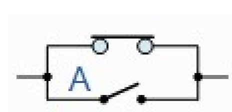
NOR
Gate

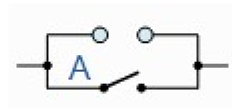
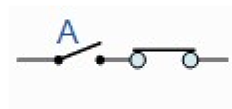
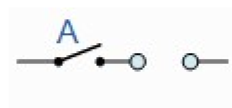
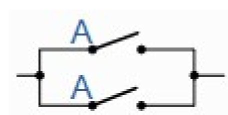
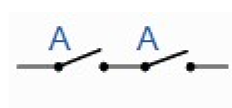
A	B	C
0	0	1
0	1	0
1	0	0
1	1	0

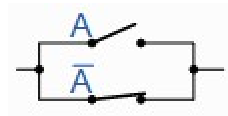
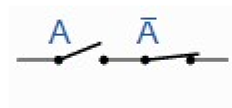
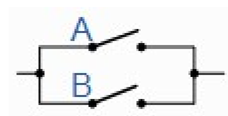
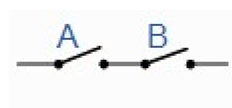


NOR
Equivalent Circuit

Laws of BOOLEAN Algebra:

Boolean Expression	Description	Equivalent Switching Circuit	Boolean Algebra Law or Rule
A + 1 = 1	A in parallel with closed = "CLOSED"		Annulment

A + 0 = A	A in parallel with open = "A"		Identity
A . 1 = A	A in series with closed = "A"		Identity
A . 0 = 0	A in series with open = "OPEN"		Annulment
A + A = A	A in parallel with A = "A"		Idempotent
A . A = A	A in series with A = "A"		Idempotent
NOT A = A'	NOT NOT A (double negative) = "A"		Double Negation

$A + A' = 1$	A in parallel with NOT A = "CLOSED"		Complement
$A \, . \, A' = 0$	A in series with NOT A = "OPEN"		Complement
$A+B = B+A$	A in parallel with B = B in parallel with A		Commutative
$A.B = B.A$	A in series with B = B in series with A		Commutative
$(A+B)' = A'.B'$	invert and replace OR with AND		de Morgan’s Theorem
$(A.B)' = A'+B'$	invert and replace AND with OR		de Morgan’s Theorem

Assignment:

1. Draw the following logic diagrams

a. A.(B+C ')= Output

b. $A^{'}$(B+C) = Output

2. Prove that, A+BC = A.B + A.C according to BOOLEAN algebra.

3. Show the ladder logic diagrams for the three fundamental logic expressions (AND,OR, NOT)

Experiment 2

Pneumatic Control System (Pneumatic Trainer)

Objective: The objective of the experiment is to get acquainted with different types of control systems, components of pneumatic control system and its application.

Pneumatic Control System: Pneumatics is a branch of engineering that makes use of gas or pressurized air. Pneumatic systems used extensively in industry are commonly powered by compressed air or compressed inert gases. A centrally located and electrically powered compressor powers cylinders, air motors, and other pneumatic devices. A pneumatic system controlled through manual or automatic solenoid valves is selected when it provides a lower cost, more flexible, or safer alternative to electric motors and actuators.

Factory-plumbed pneumatic-power users need not worry about poisonous leakage, as the gas is usually just air. Smaller or stand-alone systems can use other compressed gases that present an asphyxiation hazard, such as nitrogen—often referred to as OFN (oxygen-free nitrogen) when supplied in cylinders.

Any compressed gas other than air is an asphyxiation hazard—including nitrogen, which makes up 78% of air. Compressed oxygen (approx. 21% of air) would not asphyxiate, but is not used in pneumatically-powered devices because it is a fire hazard, more expensive, and offers no performance advantage over air.

Portable pneumatic tools and small vehicles, such as Robot Wars machines and other hobbyist applications are often powered by compressed carbon dioxide, because containers designed to hold it such as soda stream canisters and fire extinguishers are readily available, and the phase change between liquid and gas makes it possible to obtain a larger volume of compressed gas from a lighter container than compressed air requires. Carbon dioxide is an asphyxiate and can be a freezing hazard if vented improperly. Some other common uses of pneumatic system are lifts, bus doors etc.

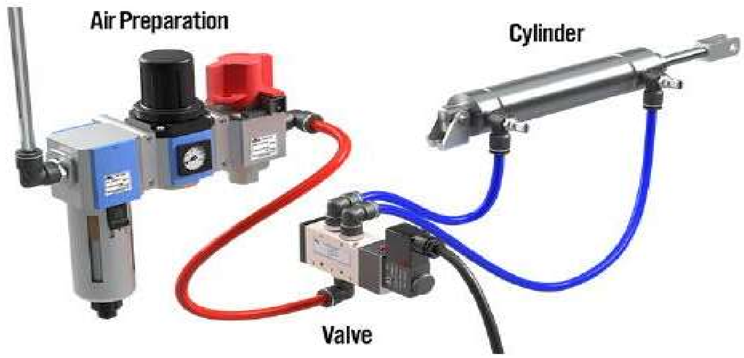


Figure 1C : Basic pneumatic system

Comparison to hydraulics:

Advantages of pneumatics:

- Simplicity of design and control—Machines are easily designed using standard cylinders and other components, and operate via simple on-off control.
- Reliability—Pneumatic systems generally have long operating lives and require little maintenance. Because gas is compressible, equipment is less subject to shock damage. Gas absorbs excessive force, whereas fluid in hydraulics directly transfers force. Compressed gas can be stored, so machines still run for a while if electrical power is lost.
- Safety—There is a very low chance of fire compared to hydraulic oil. Newer machines are usually overload safe.

Advantages of hydraulics:

- Liquid does not absorb any of the supplied energy.
- Capable of moving much higher loads and providing much higher forces due to the incompressibility.
- The hydraulic working fluid is basically incompressible, leading to a minimum of spring action. When hydraulic fluid flow is stopped, the slightest motion of the load releases the pressure on the load; there is no need to "bleed off" pressurized air to release the pressure on the load.
- Highly responsive compared to pneumatics.
- Supply more power than pneumatics.
- Can also do many purposes at one time: lubrication, cooling and power transmission.

Components of a Pneumatic Control System:

1. Sensor: A sensor is like a brain of a control system. It does not execute an action but it signals the actuator when to execute the required actions and accordingly it runs the total systems. There are several types of sensors like light sensor, proximity sensor, motion sensor etc.

2. Actuator: The actuator is like the hand or leg of a control system. It executes the required action in response to the signal of the sensor. There are two types of actuators used in a pneumatic system

a. Single Acting Cylinder (SAC): It has only one port for inlet and outlet of gas or air. It has a restoring force (spring) to come back to its initial position without any impact of air. It can be operated with a single 3 port valve.

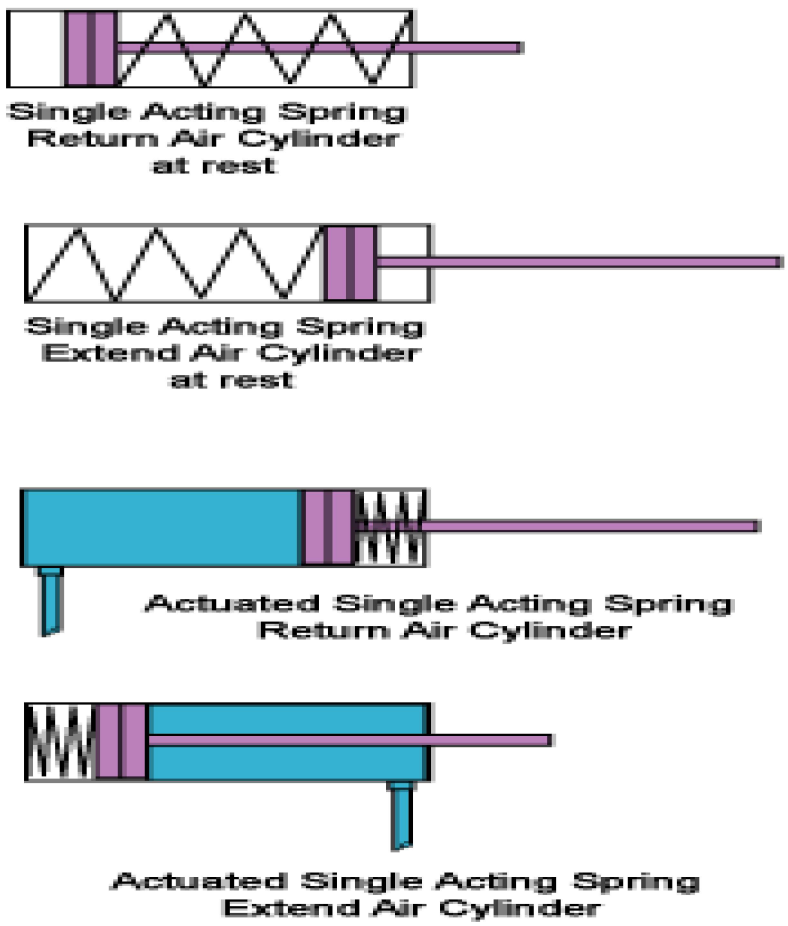
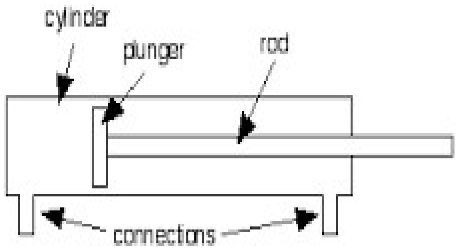
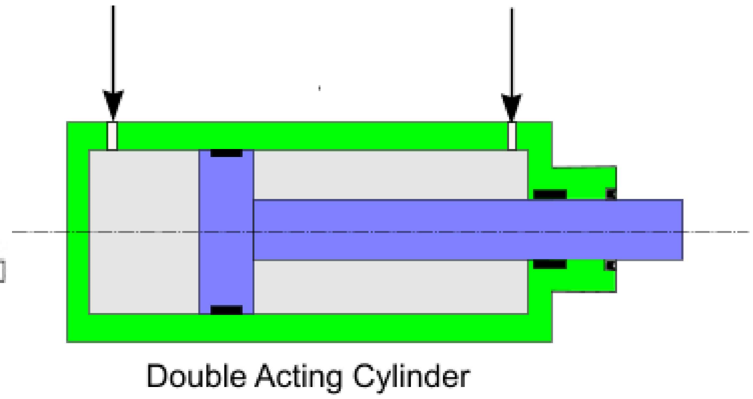


Figure: Single Acting Cylinder

b. Double Acting Cylinder(DAC): It has two ports, one inlet and one outlet port for air in and out. It has no restoring force attached to it. To operate a double acting cylinder, two 3-port valves or a single 5-port valve is required.





3. Valves: Two types of valves are used to operate the actuators of a pneumatic system.

a. 3-port valve : It has only three ports along with a maximum of one connections between them and one port always open. A 3-port valve can be lever operated or push/pull switch operated. In any position of the lever/switch if port 1 is connected to port 2 then in the other position port 2 will be connected to port 3 leaving port 3 open in one position and port 1 open in the next. The follwing figures show a lever operated and a push-pull operated 3 port valves.

Figure: 3-port Valve

5-port valve: : It has 5 ports along with a maximum of two connections between them and two ports always open. A port can be lever operated or push/pull switch operated. The advantage of a 5-port valve is that it can handle a DAC on its own whereas in case of 3-port valves two are simultaneously required to be operated to handle a DAC. Moreover a 5-port valve can be used as a 3-port valve as well.

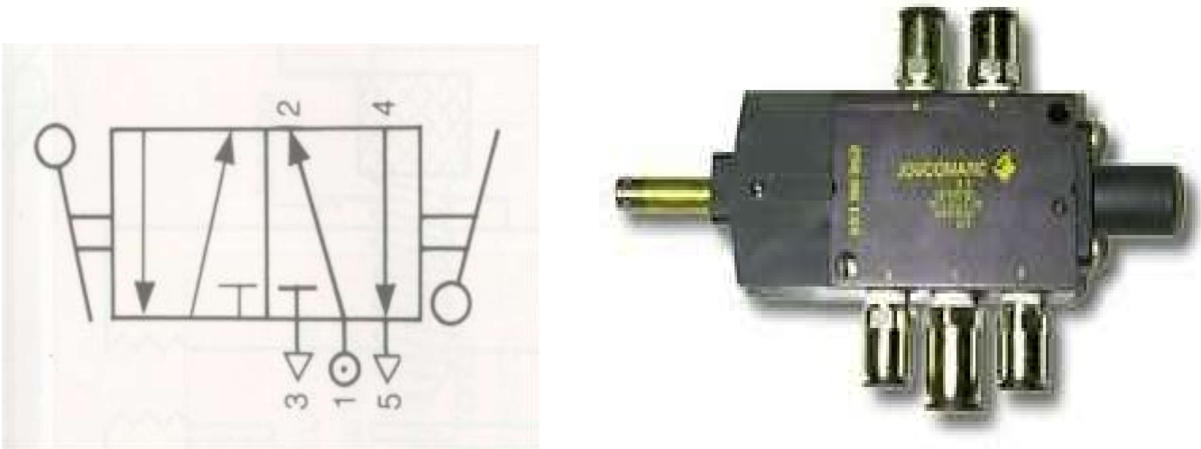


Figure: 5-port valve

In your control you will be demonstrated the actions of a pneumatic system through a pneumatic trainer which uses air as power input.

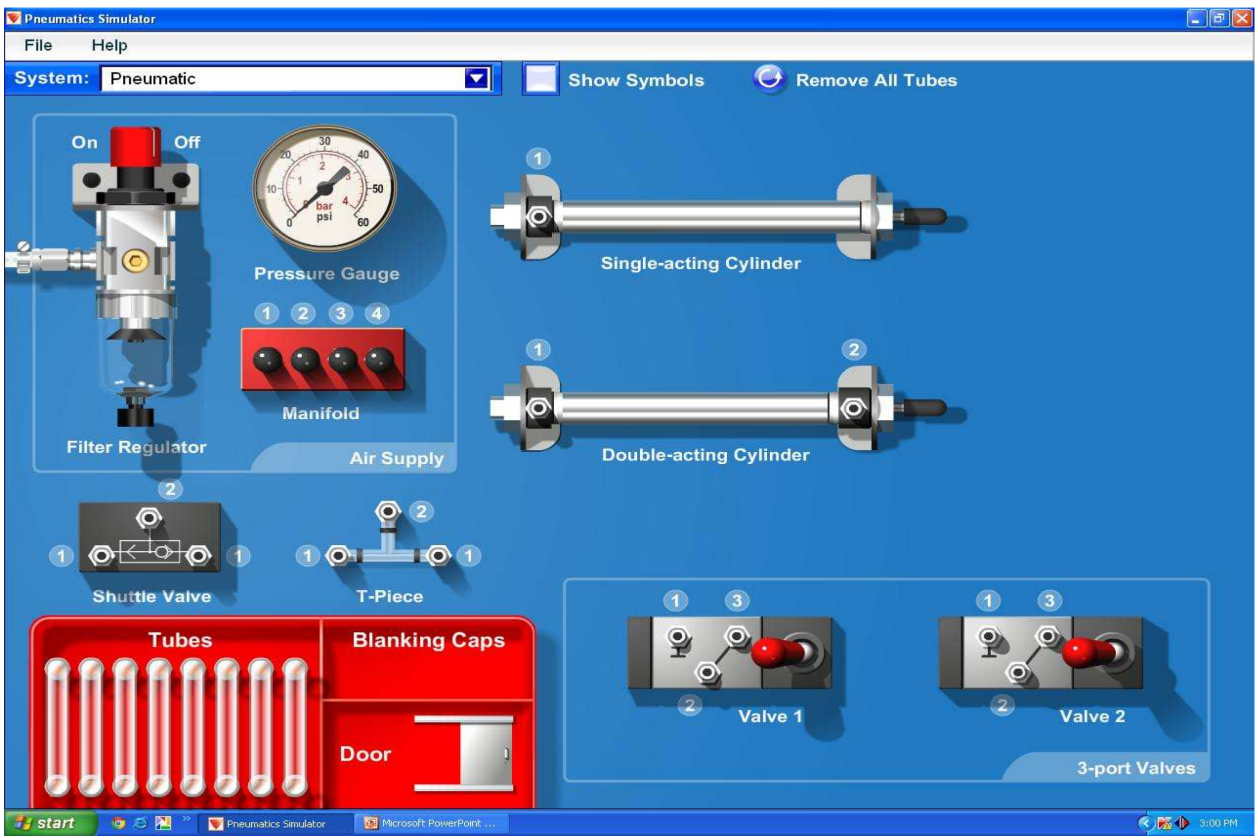


Figure: Pneumatic trainer simulation

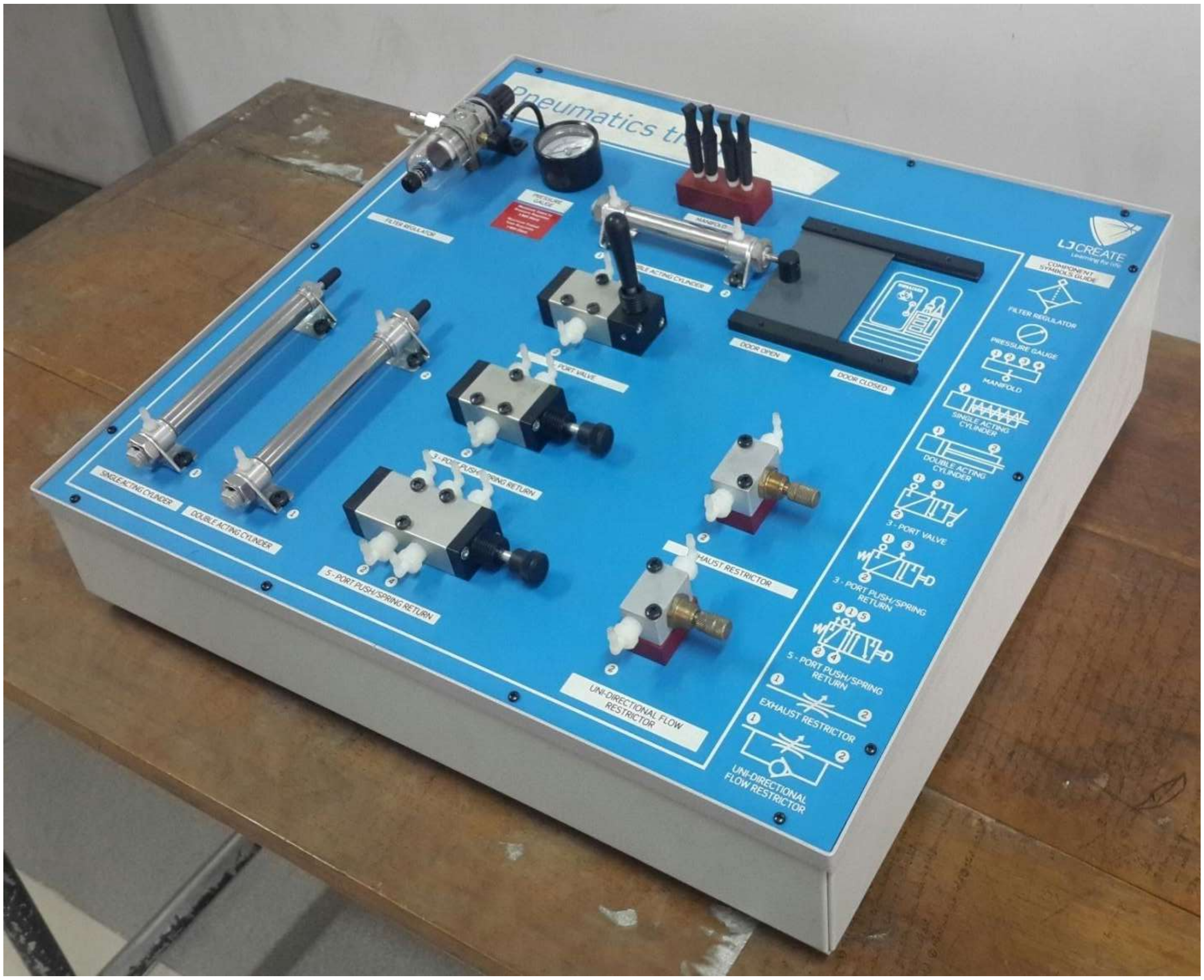


Figure: Pneumatic Trainer

Assignment:

1. What are the advantages of a pneumatic system over a hydraulic one?

2. If you are driving a car on highway would you recommend a pneumatic break system in it? Why?

3. Is there any way a DAC can be operated with a single 3-port valve? If yes/no, why?

Experiment 3

Electro-Pneumatic Control System

Objective: The purpose of this experiment is to get exposure to a practical implementation of combination of pneumatic control system and PLC logics.

Electro pneumatic control: A electro pneumatic control system uses compressible fluid as its input power and facilitates automation through the use of PLC logics. So it is actually a combination of a pneumatic and an electronic system.

In this experiment you will be illustrated an action of the electro-pneumatic trainer which will be powered by the pneumatic trainer shown in previous experiment. And several logic gates will be used to design a circuit which will facilitate the disposal of two different items in two different bins. The pneumatic trainer has 3 cylinders to push the object to be disposed, One solenoid valve to take pneumatic input and power the cylinders and three sensors (Dispenser sensor, Check point sensor and transparency sensor). There is a PLC board attached to it to design the circuit to perform required actions. The sequence of operations can be controlled both manually and automatically. The following diagrams shows the Electro-Pneumatic trainer of this experiment

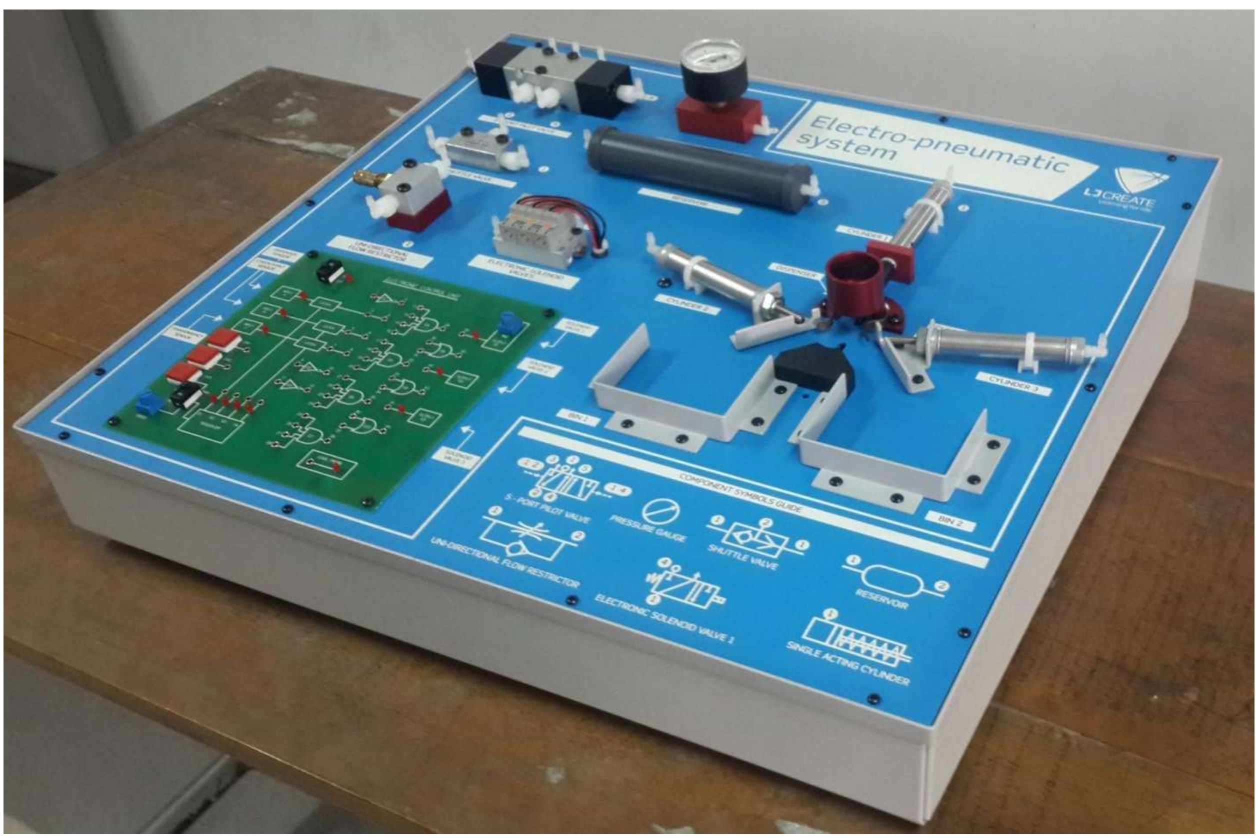


Figure: Electro-pneumatic trainer

Experimental details will be taught in the lab experiment. And the simulation of the device will also be illustrated during the experiment.

Assignments

1. Draw the logic diagram of the that was designed in this experiment.

2. Draw the block diagram of the solenoid valve used in this experiment.

Experiment 4

Proportional Integral Derivative Pressure Control System

Objective: The objective of this experiment is to learn the mechanism of PID control system and its industrial applications.

Theory: A proportional–integral–derivative controller (PID controller) is a control loop feedback mechanism (controller) commonly used in industrial control systems. A PID controller continuously calculates an error value as the difference between a desired set point and a measured process variable and applies a correction based on proportional, integral, and derivative terms, respectively (sometimes denoted P, I, and D) which give their name to the controller type. The controller attempts to minimize the error over time by adjustment of a control variable u(t), such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum:

$$u(t) = K_P e(t) + K_d \frac{de(t)}{dt} + K_I \int_0^t e(t)dt$$

where K_P , K_I and K_d , all non-negative, denote the coefficients for the proportional, integral, and derivative terms, respectively (sometimes denoted P, I, and D). In this model:

- P accounts for present values of the error. For example, if the error is large and positive, the control output will also be large and positive.
- I accounts for past values of the error. For example, if the current output is not sufficiently strong, the integral of the error will accumulate over time, and the controller will respond by applying a stronger action.
- D accounts for possible future trends of the error, based on its current rate of change

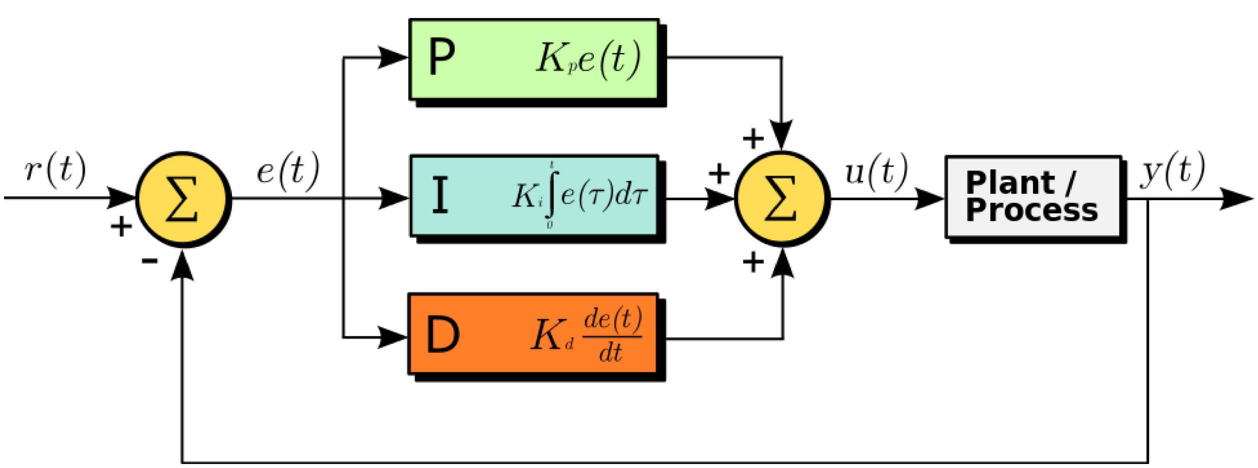


Figure: A schematic of PID control system

As a PID controller relies only on the measured process variable, not on knowledge of the underlying process, it is broadly applicable. By tuning the three parameters of the model, a PID controller can deal with specific process requirements. The response of the controller can be described in terms of its responsiveness to an error, the degree to which the system overshoots a set point, and the degree of any system oscillation. The use of the PID algorithm does not guarantee optimal control of the system or even its stability.

Some applications may require using only one or two terms to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller is called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value.

For discrete-time systems, the term PSD (proportional-summation-difference) is often used.

Proportional Term: The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain constant.

The proportional term is given by,

$P_{out} = K_P e(t)$

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (see the section on loop tuning). In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change.

Integral Term: The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain (K_i) and added to the controller output.

The integral term is given by

$I_{out} = K_I \int_0^t e(t)dt$

The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value (see the section on loop tuning).

Derivative term: The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d.

The derivative term is given by,

$D_{out} = K_d \frac{de(t)}{dt}$

Derivative action predicts system behavior and thus improves settling time and stability of the system. An ideal derivative is not causal, so that implementations of PID controllers include an additional low-pass filtering for the derivative term to limit the high-frequency gain and noise. Derivative action is seldom used in practice though – by one estimate in only 25% of deployed controllers because of its variable impact on system stability in real-world applications.

Loop tuning: Tuning a control loop is the adjustment of its control parameters (proportional band/gain, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response. Stability (no unbounded oscillation) is a basic requirement, but beyond that, different systems have different behavior, different applications have different requirements, and requirements may conflict with one another.

PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, and more sophisticated techniques are the subject of patents; this section describes some traditional manual methods for loop tuning.

Designing and tuning a PID controller appears to be conceptually intuitive, but can be hard in practice, if multiple (and often conflicting) objectives such as short transient and high stability are to be achieved. PID controllers often provide acceptable control using default tunings, but performance can generally be improved by careful tuning, and performance may be unacceptable with poor tuning. Usually, initial designs need to be adjusted repeatedly through computer simulations until the closed-loop system performs or compromises as desired.

Some processes have a degree of nonlinearity and so parameters that work well at full-load conditions don't work when the process is starting up from no-load; this can be corrected by gain scheduling (using different parameters in different operating regions).

There are two types of tuning system,

Manual tuning where the parameters are manually controlled to optimize the output and the other is **software controlled** where the parameters are controlled by the software to get the desired set point for both input and output control loop.

Experimental device: The pressure control device we use in our experiment is PCT 53 pressure control device. It is software operated and the parameters can be manually or automatically controlled. Both will be9 demonstrated in your experiment.

Figure: PID pressure control device

The software simulates the graphical representation of pressure change with time along with the numerical values of the set parameters and set point. There are four valves in the device along with a solenoid valve, one input valve, one output valve and an emergency valve to protect air entrapping.

Limitations of PID: While PID controllers are applicable to many control problems, and often perform satisfactorily without any improvements or only coarse tuning, they can perform poorly in some applications, and do not in general provide optimal control. The fundamental difficulty with PID control is that it is a feedback control system, with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise. While PID control is the best controller in an observer without a model of the process, better performance can be obtained by overtly modeling the actor of the process without resorting to an observer.

PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or hunt about the control setpoint value. They also have difficulties in the presence of non-linearities, may trade-off regulation versus response time, do not react to changing process behavior (say, the process changes after it has warmed up), and have lag in responding to large disturbances.

The most significant improvement is to incorporate feed-forward control with knowledge about the system, and using the PID only to control error. Alternatively, PIDs can be modified in more minor ways, such as by changing the parameters (either gain scheduling in different use cases or adaptively modifying them based on performance), improving measurement (higher sampling rate, precision, and accuracy, and low-pass filtering if necessary), or cascading multiple PID controllers.

Another problem faced with PID controllers is that they are linear, and in particular symmetric. Thus, performance of PID controllers in non-linear systems (such as HVAC systems) is variable. For example, in temperature control, a common use case is active heating (via a heating element) but passive cooling (heating off, but no cooling), so overshoot can only be corrected slowly – it cannot be forced downward. In this case the PID should be tuned to be overdamped, to prevent or reduce overshoot, though this reduces performance (it increases settling time).

Assignment:

1. Why is PID suboptimal in case of non-linearities?

2. What problems may arise if the differential part is missing in a PID?

3. What are the limitations of a PID?

4. Mention a few industrial applications of PID.