IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X,
PP 36-45
www.iosrjournals.org

Design And Develop Of Strive Free Fluid Pressure Regulator

M. B. Chopade and Prof. Dr. A.M. Badadhe
[1,2] *(Mechanical (Design), Pune University, India)*

Abstract: *This research paper presents novel design relates to balanced fluid pressure regulating valve on reducing higher pressure forces towards adjusting knob device which is less than 0.4 N.m. Pressure regulator design with effortless operating safe condition by considering Pressure Vessel calculations towards Pressure Equipment Directive up to 20 bar operating fluid pressure. Proposed modular design reduces the potential effort during pressure regulating at higher pressure ranges and increases the safety level which offers the most precise controllability. Engineering Calculation comply the PED 97/23/EC Pressure Equipment Directive and EN 13463-1 non-electrical equipment for use in potentially explosive atmospheres. Fluid pressure regulators comprise a valve actuated by an expansible chamber device subject to the outlet pressure and a regulating or calibrating spring for determining the pressure to be maintained. Pressure regulators are meant for frequent pressure adjustments, and then the problem for operator to adjust the pressure as manual efforts are required is really high. This design offers strive free operating balanced pressure regulator control at higher pressure range.*

Keywords: *Pneumatic Regulator, effortless operating, pressure vessel, PED*

I. Introduction

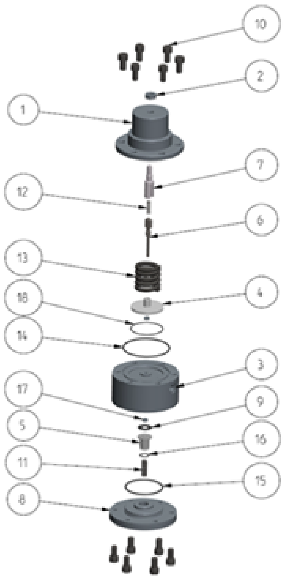
A Fluid pressure regulator having a piston subject on opposite sides to outlet pressure and a reference pressure to automatically move to a position of balance of pressure by varying the flow through the regulator outlet. The present development relates to fluid pressure systems and more particularly to an improved pressure regulator therefor. Moreover, known regulators are structurally complex, of unnecessary bulk and weight, inaccurate, requires excess effort to set outlet pressure, and usually regulate fluid flow instead of fluid pressure. Accordingly, the main object of the present product enhancement is to provide an improved fluid pressure regulator which will be free of the above and other objectionable characteristics of known regulators. Fluid pressure regulators are used in a host of fluid dynamic systems to maintain certain pressures or pressure drops constant in the face of variations in system parameters and/or external disturbances. A general perception is that safety factors are there to provide confidence in the safe use of an engineering component, assembly or system. Pressure equipment by its nature is potentially hazardous and needs factors of safety to provide a margin against failure from uncertainties in design, materials, manufacture, inspection, and subsequently in operation. Different factors of safety may guard against the same uncertainty. (John Darlaston , and John Wintle, 2006) [1] In relation to uncertainty in manufacture, design standards provide for a reduction in the design safety factor with increasing inspection requirements. An example of this is the European Unfired Pressure Vessel standard, EN 13445:2002 .A statements on safety and reliability, two of which are worthy of note in the context of this paper (Petrowski H, 1994) [2]. The first one explains that failure is central to the design process in that more is learnt from failures than from success. (Darlaston J, 2007) [3] The UK and European legislation requirements on conformity assessment of 'new' equipment provide an example of factors of safety within the control and monitoring of the pressure equipment. In the Pressure Equipment Directive hazard categories are identified. The risk is defined in terms of the stored energy and the process fluid. These terms are used to determine the measures that have to be taken to demonstrate conformity with the essential safety requirements. There is increasing stringency on conformity assessment depending on hazard category. It is worthwhile examining this process as it regularizes the approach for non-nuclear components and is not far removed from the approach for nuclear components. The Directive requires that all pressure equipment and assemblies designed to operate above 0.5 bar and within its scope must be safe when placed on the market and put into service. (Xue-Song Wang, 2007) [4] Presents a dynamic model and a design method for an accurate self-tuning pressure regulator for pneumatic-pressure–load systems that have some special characteristics such as being nonlinear and time-varying. (Yong-Ku Kong, 2005) [5] The effects of gender, handle diameter (25–50 mm), and handle orientation (horizontal and vertical) on the perceived comfort, torque, total finger force, and efficiency of flexor and extensor muscle activity were examined in a maximum torque task. Summary of torque and finger forces In the horizontal orientation 4.1 Nm & in the vertical orientation 3.14 Nm for different knob diameter. The controlling legislation for placing pressure equipment on the market or putting into service within Europe comes from

European Union Directives. An important instrument is the Pressure Equipment Directive that is transposed into UK legislation as the Pressure Equipment Regulations. Annex I of the Directive (PED) defines Essential Safety requirements for pressure equipment but not the means for achieving them. The segment of industrial products, hand held products occupy a major section. An important issue in design of these products is to identify the factors that lead to human comfort and those leading to discomfort (Dhananjay Singh Bisht, 2013). 'This Paper came with design of direct acting fluid Pressure Regulator with effortless operating to have a controlled performance laterally safety conditions by considering Pressure Vessel calculations towards Pressure Equipment Directive.'

II. Methodology

Fluid Pressure regulator assembly is designed for the required life of all the components of assembly and each component is design and analyzed. Fig 1 shows the major components of the strive free pressure regulator assembly. Fluid forces are determined on the requirement of the product function. Fig 2 shows the functional performance related cross sectional view. Fluid pressure regulators or reducing valves commonly comprise a valve actuated by an expansible chamber device or piston subject to the outlet pressure and a regulating or calibrating spring for determining the pressure to be maintained. The regulating spring urges the valve away from its seat in opposition to the pressure of the fluid on piston on the outlet side of the valve; a state of equilibrium is reached at the desired outlet pressure. When the valve is closed, it is subject to inlet pressure on one side and to outlet pressure on the other and the resultant difference in pressure tends to hold the valve closed.

Table 1. Bill OF Material (BOM)



BOM

Balloon No	Part Name	Qty
1	Bonnet	1
2	Lock Nut	1
3	Valve Body	1
4	Piston	1
5	Disc Holder	1
6	Stem	1
7	Knob	1
8	End Cap	1
9	Flat Seal	1
10	Screw M10	12
11	Spring –Disc Holder	1
12	Spring-Stem	1
13	Spring-Piston	1
14	O-Ring	1
15	O-Ring	1
16	O-Ring	1
17	U Seal	2

Fig. 1 Proposed Concept Exploded view

Special arrangement of internal Piston, spring, Stem and Bonnet. It is another object to provide an improved pressure regulating valve including an arrangement for balancing the valve to prevent variations in operation due to changes in the pressure of the fluid supply. Table 2.1 shows the Force Distribution Analysis with Functional Dimensions & Force Balance Proposed modular design reduces the potential effort during adjustment of pressure regulating by the effect of mutually balanced forces of piston, spring and acting on structural parts and not on the operating adjusting forces through adjustable knob even at higher pressure ranges and increases the safety level which offers the most reliable product performance.

Pressure Regulator responds on dynamic pressure forces, which acts on the above listed components fig.1 throughout the applicable pressure range 0-20 bar.

Forces F1 to F7 listed below are for analytical calculations at sealing dimensions.

F1 Fluid Inlet pressure acts on Orifice Disc Holder

F2 Fluid Inlet pressure acts bottom side of Orifice Disc Holder

F3 Outlet pressure acts on Orifice Disc Holder

F4 Outlet pressure acts below the Orifice Disc Holder

F5 Outlet pressure acts below the Piston

F6 Stem Spring forces against the knob weight

F7 Piston Spring forces against the outlet incremental fluid forces

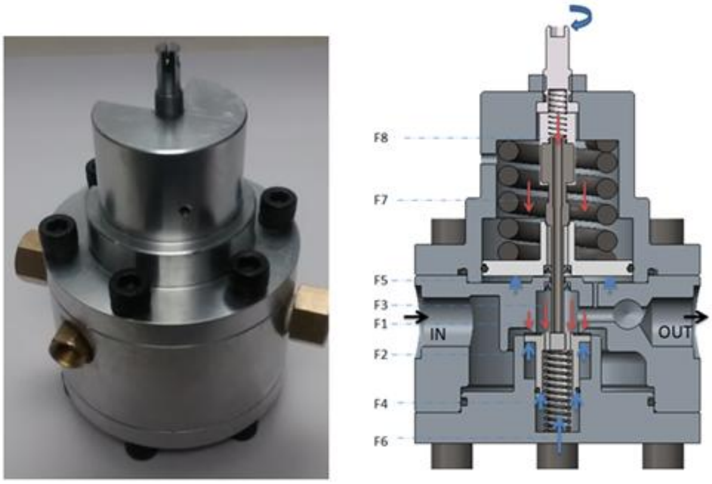


Fig. 2 Proposed Concept with cross sectional view

1.1 Force Distribution Analysis with Functional Dimensions & Force Balance:

Table 2 Inlet Pressure: 20 Bar Outlet Pressure : 20 Bar

	Pressure	Pressure		D1	D-stem	Area	Dir.	Force	Resultant
		Bar	N/mm^2	mm	mm	mm^2		N	N
F1	P in	20	2	25.5	17.00	283.7	(-)	567.5	
F2	P in	20	2	25.5	17.00	283.7	(+)	567.5	
F3	Pout	10	1	17	4.80	208.9	(-)	208.9	
F4	Pout	10	1	17	4.80	208.9	(+)	208.9	
F5	P out	20	2	58.2	4.8	2642.2	(+)	5284.5	
F6	F spring						(+)	50.0	
F7	F spring						(-)	5284.5	
							+ is closed		50

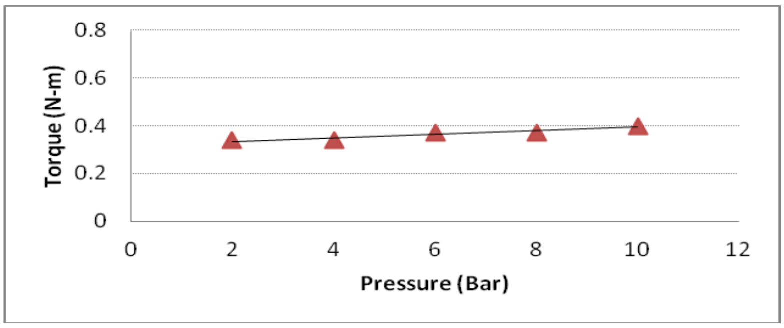
We do reflect the essential condition in order to assess the operational performance of regulators against pressure range by Force balance calculation, when operating under steady-state conditions. In this situation the valve is in equilibrium with the pressure force exactly balancing the spring force. Piston and floating stem threads are not under any spring force or not even any fluid forces which can see in table 2 at even 20 bar of fluid pressure.

Torque required to adjust the knob setting is independent of application of fluid pressure with this Concept design. Knob Diameter: 16 mm & Bottom Spring Forces applied on disc holder: 40 N to 50 N towards 10 mm travel

Table 3. Torque Calculation (BOM)

Working Pressure (Bar)	0	2	4	6	8	10
Working Pressure (MPa)	0	0.2	0.4	0.6	0.8	1
Knob C/s Area (mm2)	28.27	28.27	28.27	28.27	28.27	28.27
Fluid Thrust Force Acting on Knob(N)	0.00	0.00	0.00	0.00	0.00	0.00
Spring Force (N)	40.00	42.00	44.00	46.00	48.00	50.00
Total Force (N) = Thrust+ Spring Force	40.00	42.00	44.00	46.00	48.00	50.00
Torque Required (N-mm)	320.00	336.00	352.00	368.00	384.00	400.00
Torque Required (N-m)	0.32	0.34	0.35	0.37	0.38	0.40
Torque Required (lbf-in)	2.83	2.97	3.12	3.26	3.40	3.54

Graphical representation shows from above calculation that with increase in Pressure can be adjusted to highest value effortlessly. Piston and floating stem threads are not under any spring force or not even any fluid forces are completely balanced. Graph 1 shows a constant effort required to operate the valve, irrespective of higher fluid pressure.



Graph 1. *Pressure vs Torque*

Analytical calculation shows Torque required to adjust the knob is <0.4 N.m. Outlet pressure setting through knob is independent of application of fluid pressure with proposed concept design.

1.2 Assessment of sparks Generated By Impact:

Non-electrical equipment for use in potentially explosive atmospheres European standard EN 13463-1 Maximum allowable Impact energies according to ATEX Non- electrical=500 J

Considering Worst Case, travel of Piston against Inlet block with 10 mm stroke figure 2

Initial spring load	= 264 N
Max. Spring load	= 2642 N (after full stroke)
Inlet Pressure	= 20 bar
Outlet pressure	= 20 bar
Effective pressure	= 20 bar (worst case)
Maximum stroke (s)	= 10 mm
Weight of Moving component	=(piston + stem) = 0.185 kg
Piston Diameter	= 58.2 mm
Force (F)	= pA = 5219.572 N
Acceleration (a)	$= \frac{F}{m}$
	= 21150.12 m/s2

IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X,
PP 36-45
www.iosrjournals.org

Velocity (v) $= \sqrt{2as}$

$= 20.56702$ m/s

Impact Energy $= \frac{1}{2} mv^2$

$= 52.195$ J

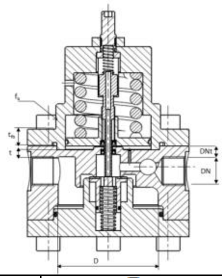
Evaluation: Calculated impact energy 52.195 J is less than 500 J according to ATEX Non- electrical. Proposed design is safe and complying Non-electrical equipment for use in potentially explosive atmospheres.

1.3 Calculation for Valve Performance against Pressure Equipment Directive:

Calculations are done considering pressure vessel aspect as product carries pressurised fluid to define the strength of the product at higher pressure range.

Table 4 Calculation for valve performance against Pressure equipment directive:

Input			
Parameters	Symbols	Values	Units - IPS
Material Properties			
Aluminium 6026-T9 : Valve Body Components			
Modulus Of Elasticity	E_{al}	70.0	GPa
Tensile Strength	σBb	240	MPa
0.2% Yield Limit	Rpb	160	MPa
Carbon Steel H.R.3000: Fastener			
Tensile Strength	σBb	827.37	MPa
Yield Limit =σBb*0.8	Rpb	661.897	MPa
Stainless Steel AISI 305 : Spring			
Modulus Of Elasticity	Ebr	200	GPa
Tensile Strength	σBb	586	MPa
0.2% Yield Limit	Rpb	207	MPa
Calculations			
1. STRESS IN BODY BY INTERNAL PRESSURE			
Pipe Size: 1/2" DN15 (20.95 mm Outside Dia.)			
Maximum operating pressure differential (MOPD)	PS	1	Bar
Safe working pressure (SWP)	PW	20	Bar
Minimum burst pressure (according to calculation)	P	40	Bar
Safety factor on MOPD	$v = \frac{P}{PS}$	40	Bar
Pressure Regulator Body Specification			
Pipe Size DN15	DN	20.95	mm
Wall thickness body at pipe connection	DNt	5	mm
Inside diameter of body	D	58	mm
Wall thickness of body	t	4	mm
Flange thickness of body or thread depth of screws (smallest value)	tfb	8	mm
Body material Aluminium 6026-T6	Matbody		



Inside radius of body	$Ri = \frac{D}{2}$	29	mm
Outside radius of body	$Ru = \frac{D}{2} + t$	34	mm
Values To Be Calculated			
Longitudinal Stress	$\sigma 1 = \frac{P \times Ri^2}{Ru^2 - Ri^2}$	10.68	MPa
Maximum circumferential stress at wall	$\sigma 2 = P[\frac{Ru^2 + Ri^2}{Ru^2 - Ri^2}$	25.36	MPa
Maximum radial stress at	σ3 = (-P)	-4.00	MPa
Maximum equivalent stress at wall	$\sigma_e = \sqrt{\sigma 1^2 + \sigma 2^2}$	34.19 1	MPa
Result: Here σe <Mat_{body} : Maximum equivalent stress at wall are Safe; value is below the maximum allowable stress			
1.1) Calculation of stress in body, caused by force applied on pipe. Forces acting on pipe and body according to EN 161			
Bending moment on 1/2" pipe	M15	105	N.m
Section modulus of minimum cross section of pipe connection	$W_p := \frac{\pi}{32} \cdot \frac{\left[(DN + 2 \cdot DN_t)^4 - DN^4\right]}{(DN + 2 \cdot DN_t)}$	2300	mm^3
Maximum bending stress at pipe connection	$\sigma_b = \frac{M}{Wp}$	45.66	MPa
Result: Maximum bending stress at pipe connection is σ_b < Mat_{body}; value is below the maximum allowable stress			
1.2) Calculation of stress in body, caused by torque applied on pipe, Torque acting on pipe and body pipe according to EN 161			

Torque on 1/2" pipe (DN15	T15	50	N.m
Maximum torque to be applied on pipe connection	T	50	N.m
Section modulus of minimum c/s of pipe connection	$W_t := \frac{\pi}{16}\cdot\frac{\left[(DN + 2\cdot DN_t)^4 - I\right.}{(DN + 2\cdot DN_t)}$	4599	mm^3
Maximum shear stress at cross-section at pipe connection	$\tau t = \frac{T}{W_t}$	10.872	MPa
Result: Maximum shear stress at pipe connection is τt <0.67. Mat_{body} ; value is below the maximum allowable stress			

Design has been evaluated through analytical calculation and stress are below the maximum allowable stress at higher working pressure i.e. 20 bar. Direct acting Pressure regulator at higher pressure range, which generally not easily available in market.

III. Fea Results And Discussion

Equivalent Stress Plot: 3D CAD model is created in Pro-Engineering to define the Functional dimension analysis and Fit function analysis. FEA is performed in ANSYS workbench.

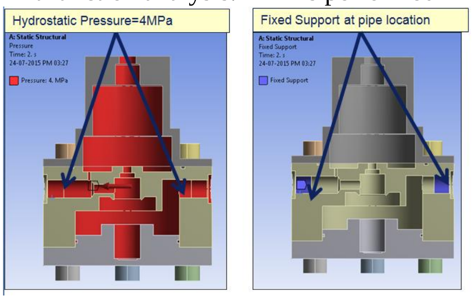


Fig. 3 Boundary conditions Internal Pressure=40 Bar & Constrained Pipe Location in body.

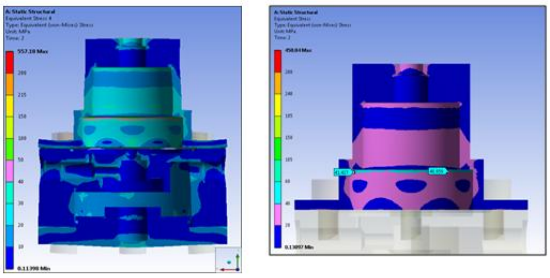


Fig. 4 FEA Simulation stress distribution

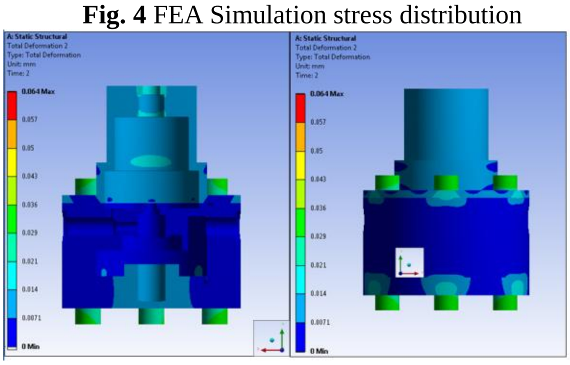


Fig.5 Displacement plot

Result: Maximum Sum Displacement 0.064 mm (red contour) occurs in Valve Body. This new Design has been done to perform valve function at higher pressure condition up to 20 bar internal pneumatic pressure.

1.4 FEA & Analytical Result Correlation:

Correlation analysis gives a confidence about product safety as FEA and analytical calculation are closely matching and stresses induced are below the yield strength.

Table 5. FEA & Analytical Result Correlation

	Analytical (MPa)	FEA (MPa)
σe=Stress in body by internal pressure	34.191	34.524
σbo =Maximum bending stress	39.422	41.47

IV. Experimental Test Set Up and Conclusion

Test set up has been made to evaluate the Torque required towards knob to adjust the outlet pressure. Fig 8 Operating Pressure range 0 to 20 bars.

To observer the effort required to control the outlet pressure through knob used digital Torque Wrench. Pressure Regulator is connected to supply port 1 pressure which comes from compressed air. Inlet compressed air is P1 is 10bar kept at constant thought the testing. The function of pressure regulator is to reduce a pressure and to keep outlet pressure as constant as possible while the inlet pressure and the flow may vary. Outlet pressure controlled in the range of 1 to 10 bars, Readings are taken in Pressure dial gauge and with every increment in pressure the effort required to rotate the knob is taken by digital torque Wrench. Three readings are taken periodically after interval of one day.

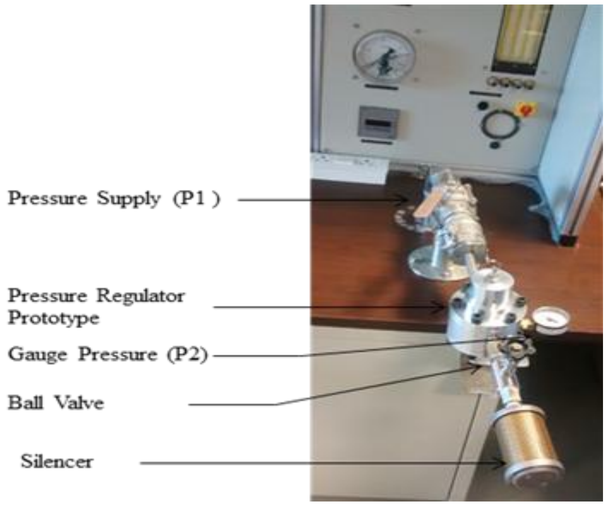


Fig. 6 Experimental Test Setup

Results: Torque required to adjust the knob setting is independent of application of fluid pressure with this Concept Effortless Pressure Regulator design, new designed and evaluated torque is <0.4 N.m

Table 6: Test Observation by Digital Torque Wrench

Sr. Sr No	**Inlet** (Bar)	**Outlet** (Bar)	**Torque** Reading 1	Reading 2	Reading 3
1	10	1	0.1	0.11	0.1
2	10	2	0.1	0.11	0.12
3	10	3	0.25	0.24	0.25
4	10	4	0.3	0.24	0.3
5	10	5	0.35	0.3	0.32

6	10	6	0.36	0.34	0.36
7	10	7	0.37	0.36	0.37
8	10	8	0.38	0.39	0.38
9	10	9	0.4	0.39	0.39
10	10	10	0.38	0.4	0.4

V. Conclusions

The main objective of the present development is to provide an improved fluid pressure regulator which offers strive free operating with balanced condition. Reducing higher pressure forces towards adjusting knob device, new design with effortless operating (Torque<0.4 N-m)

A thought process of design and develop of effortless operating regulator is successfully developed and evaluated through FEA, analytical calculations and prototype testing.

A Design on safety conditions by systematic study of dynamic Force inside the Pressure regulator component. Proposed design is safe and complying Non-electrical equipment for use in potentially explosive atmospheres.

Acknowledgment

I wish to express my sincere thanks to Prof. Dr. Avinash Badadhe for guidance and encouragement in carrying out project work. I express our sincere thanks to Dr. A.A. Pawar, HOD of Mechanical Department.

References

[1]. John Darlaston, John Wintle, 2007, Safety factors in the design and use of pressure equipment, Elsevier Science Inc, Engineering Failure Analysis 14, pp. 471–480
[2]. Petrowski H. Design paradigrams: case histories of error and judgement in engineering. Cambridge: Cambridge University Press; 1994.
[3]. Darlaston J. and Wintle J., 2007, “Safety factors in the design and use of pressure equipment” Elsevier Inc, Engineering Failure Analysis 14, pp. 471-480
[4]. Xue-Song Wang et. al “Modeling and self-tuning pressure regulator design for pneumatic-pressure–load systems” Science Direct, Control Engineering Practice 15 (2007) 1161–1168
[5]. Yong- Ku Kong,et. al “Evaluation of handle diameters and orientations in a max-imum torque task” Elsevier Science Inc, International Journal of Industrial Ergo-nomics 35 (2005) 1073–1084
[6]. A. Nabi, E. Wacholder, et al. 2000, “Dynamic Model for a Dome-Loaded Pressure Regulator” Trans ASME, Journal of Dynamic Systems, Measurement, and Control, Vol. 122,pp. 290-297
[7]. Afshari H., Zanj A. et al, 2010, “Dynamic analysis of a nonlinear pressure regulator using bondgraph simulation technique” Elsevier Science Inc, Simulation Modelling Practice and Theory 18, pp. 240–252
[8]. Arteaga-P M.A._erez, Alejandro Guti_errez-Giles ,et al (2015) “On the Observability and the Observer Design of Differential Pneumatic Pistons” Transactions of the ASME Journal of Dynamic Systems, Measurement, and Control, AUGUST 2015, Vol. 137
[9]. Burdekin F.M., 2007, “General principles of the use of safety factors in design and assessment” Elsevier Science Inc, Engineering Failure Analysis 14, pp. 420–433.
[10]. Fletcher I., et al, 1996 “Modelling of a two-stage high-pressure gas reduction station”, Elsevier Science Inc., Appl. Math. Modelling, Vol. 20, October, pp.741-749
[11]. Hubbard Mont, 2002 “Effects of Diaphragm Compliance on Spring-Diaphragm Pressure Regulator Dynamics”, Trans. ASME, Vol. 124, pp. 290-296
[12]. Joel A. Cort, Jim R. Potvin, 2011, “Maximum isometric finger pull forces” Elsevier Science Inc, International Journal of Industrial Ergonomics 41, pp.91-95
[13]. Kong Yong-Ku, Brian D. Lowe, 2005 “Evaluation of handle diameters and orientations in a maximum torque task” Elsevier Science Inc, International Journal of Industrial Ergonomics 35, pp.1073–1084.
[14]. Marco A. Arteaga-P_erez, et al, 2015, On the Observability and the Observer Design of Differential Pneumatic Pistons, Trans. ASME, Journal of Dynamic Systems, Measurement, and Control, Vol. 137, pp. 081006-1-25
[15]. Rami E.G. et al, 2007 “Modelling of a pressure regulator ” Elsevier Science Inc, International Journal of Pressure Vessels and Piping 84, pp. 234–243.
[16]. Tsai Chiung-Wen ,et al, 2012, “Parametric analysis of pressure control system for Lungmen nuclear power plant” Elsevier Science Inc., Energy Procedia 14, pp.1082–1086.
[17]. Zafer N. and Luecke G., 2008, “Stability of gas pressure regulators” Elsevier Science Inc, Applied Mathematical Modelling 32, pp. 61–82

[18]. Zhipeng Xu, et al., 2011,"Development of a Novel High Pressure Electronic Pneumatic Pressure Reducing Valve" ASME J. Dyn,, Measurement, and Control, Journal of Dynamic Systems, Measurement, and Control, Vol. 133 / 011011-1.
[19]. DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 8 June 2011, on the restriction of the use of certain hazardous substances in electrical and electronic
[20]. I.S. EN 13611:2007+A2:2011, EUROPEAN STANDARD, October 2011
[21]. EN 13463-1, Non-electrical equipment for use in potentially explosive atmos-pheres-part 1: Basic method and requirement, January 2009
[22]. 6056006, (United States Patent), May 2, Piston Pressure Regulator, 2000
[23]. US7836911 B2, (United States Patent), Nov 23, Gas pressure regulator with a valve and piston assembly, 2010
[24]. US4840195A(United States Patent), Jun 20, Piston-backed gas pressure regulator, 19894
[25]. Roark & Young, Formulae for stress and strain (Fifth edition), 504 (case 1B), 363 (case 10b)