Artificial Neural Network Modeling & Control For Pressurized Head Box of Paper Machine

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ABSTRACT

A dynamic model for pressurized head box of high speed paper machine is considered. Analysis procedures enable to anticipate the automation in the head box. An optimum, minimum control effort strategy is proposed. Simulated open and closed loop response records are computed. The simulated data has been used for training the neural network. Artificial neural network(ANN) model minimizes the interaction between physical parameters. In this paper, an ANN controller has been designed for headbox and both the controllers namely PID and ANN have been compared.

Keywords: ANN, Headbox, paper machine, modeling, control,

Introduction

In paper industry, the high speed paper machine is equipped with pressurized flow box with air cushion. For complete automation, it is necessary to know dynamic processes which are associated with the incoming and outgoing stock on the paper machine wire. The pressurized headbox is shown in fig.1. The headbox arrangement will produce output interaction between air pressure and stock level. In present trend of the process industry, the complex system can not be handled with classical controller(PID). For this purpose, ANN has been designed and compare both controllers.

2. Dynamic model of pressurized headbox:

The stock flow affects the stock level and other physical parameters. The headbox model is derived in three ways as under.

2.1 When portion of box filled with stock:

For equilibrium condition

$dm_{fb}/dt = m_{in} - m_{out} - m_{ol}$ [1]

Equation[1] may be represented by the relationship

$d\Delta m_{fb}/dt = \Delta m_{in} - \Delta m_{out} - \Delta m_{ol}$ [2]

Amount of stock present in the flow box,

$m_{fb} = V_1 \rho_s$ or $A_{fb} h_1 \rho_s$

or $\Delta m_{fb} = A_{fb} \Delta h_1 \rho_s$

or $\Delta m_{fb} = A_{fb} h_1 \infty \upsilon_1 \rho s$; $\Delta m_f = m_{fb} \infty \upsilon_1$

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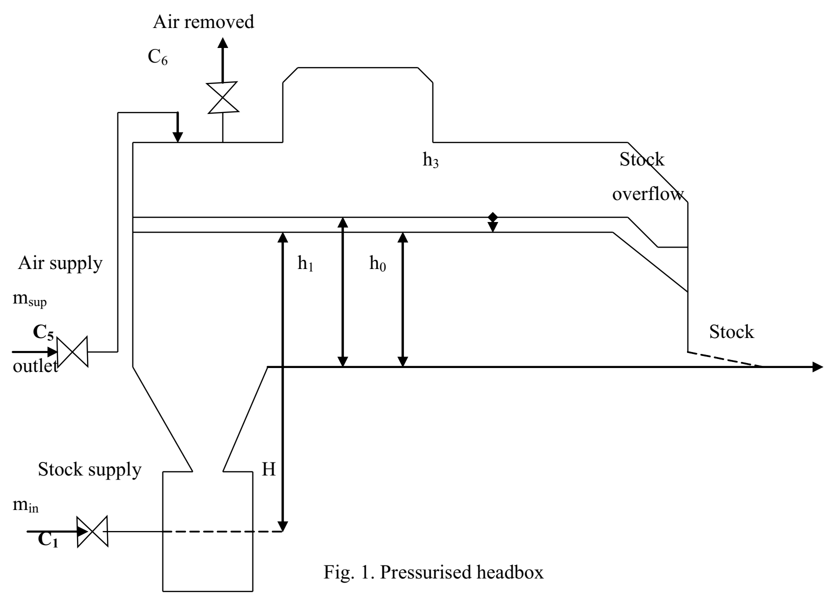


Fig. 1. Pressurised headbox

Amount of inlet stock m_{in} depends on opening of inlet valve C_1, therefore the pressure of stock before and after the valve P_{11} & $P_{12.}$

$m_{in} = m_{in}(C_1, P_{11,} P_{12})$

$\Delta m_{in} = (\partial m_{in}/\partial C_1) \infty \Delta C_1 + (\partial m_{in}/\partial H) \infty \Delta P_{11} + (\partial m_{in}/\partial P_1) \infty \Delta P_{12}$ [3]

Assume that the characteristic of inlet valve of stock is linear, then

$(\partial m_{in}/\partial C_1) \infty = m_{inmax}/C_{1max}$; $(\partial m_{in}/\partial C_1) \infty \Delta C_1 = (m_{inmax}/C_{1max}) \Delta C_1$

$(\partial m_{in}/\partial C_1) \infty \Delta C_1 = m_{inmax} \mu_1$ [4]

Flow of stock through the regulating valve amount to

$m_{in} = A_c . C_d \sqrt{2} \rho_s (P_{11} - P_{12})$ or $(\partial m_{in}/\partial H) \infty \Delta P_{11} = -1/2 m_{in} \infty \rho_s g(h_1 \infty / P_{11} - P_{12}) \upsilon_1$ [5]

$(\partial m_{in}/\partial P) \infty \Delta P_{12} = -1/2\, m_{in} \infty (P \infty / P_{11} - P_{12}) P'$ [6]

Flow of stock from slice lip

$m_{out} = m_{out}(C_2, h_{1,} P)$, C_2 is the slice opening

$\Delta m_{out} = (\partial m_{out}/\partial C_2) \infty \Delta C_2 + (\partial m_{out}/\partial h_1) \infty \Delta h_1 + (\partial m_{out}/\partial P) \infty \Delta P$ [7]

if slice opening is linear then

$(\partial m_{out}/\partial C_2) \infty = m_{outmax}/C_{2max}$ or $(\partial m_{out}/\partial C_2) \infty \Delta C_2 = (m_{outmax}/C_{2max}) \Delta C_2$

or $(\partial m_{out}/\partial C_2) \infty \Delta C_2 = m_{outmax} \mu_2$ [8]

Flow of stock through the slice

$m_{out} = A_{lip} . C_{d2} \sqrt{2} \rho_s (h_1 g \rho_s + P)$ $(\partial m_{out}/\partial h_1) \infty \Delta h_1 = 1/2\, m_{out} \infty \rho g(h_1 \infty / h_1 g \rho_s + P) \upsilon_1$ [9]

$(\partial m_{out}/\partial P) \infty \Delta P = 1/2\, m_{out} \infty (P \infty / h_1 g \rho_s + P) P'$ [10]

Flow of stock through overflow is

$m_{ol}= C_{d3} b\, \rho_s \sqrt{2g(h_3)}^{1.5}$

$\Delta m_{ol}=3/2 C_{d3} b \rho_s h_3 \infty \sqrt{2gh_3} \Delta h_3/h_3\infty$

or $\Delta m_{ol}=3/2 m_{ol}\infty\upsilon_3$ [11]

Substituting equations from 1 to 11 in equation 2,

$d(V_1 \rho_s \upsilon_1)/dt=[m_{inmax}\mu_1 -1/2\, m_{in}\infty\rho_s g(h_1\infty/ P_{11}-P_{12})\ \upsilon_1 -1/2\ m_{in}\infty\ (P\infty\ /\ P_{11}-P_{12})\ P' - m_{outmax}\mu_2\ -1/2\ m_{out}\infty\, \rho g(h_1\infty/\ h_1 g\ \rho_s+P\ )\ \upsilon_1 - 1/2\ m_{out}\infty(P\infty/\ h_1 g\ \rho_s+P)\ P' -3/2 m_{ol}\infty\upsilon_3]$

or $V_1\ \rho_s\ d\upsilon_1/dt=[m_{inmax}\mu_1 -1/2\ m_{in}\infty\rho_s g(h_1\infty\ / P_{11}-P_{12})\ \upsilon_1 -1/2\ m_{in}\infty(P\infty/\ P_{11}-P_{12})\ P'$

$-1/2\ m_{out}\infty\ \rho g(h_1\infty/\ h_1 g\ \rho_s+P\ )\ \upsilon_1 -1/2\ m_{out}\infty\ (P\infty/\ h_1 g\ \rho_s+P)\ P' -3/2 m_{ol}\infty\upsilon_3]$

$(V_1\ \rho_s\ /m_{inmax})\ {*}(d\upsilon_1/dt)= [\mu_1 -\ (m_{in}\infty/m_{inmax})\ 1/2\ \rho_s g(h_1\infty/\ P_{11}-P_{12})\ \upsilon_1 -\ (m_{in}\infty/m_{inmax})\ 1/2(P\infty/\ P_{11}-P_{12})\ P' -1/2\ \rho g(h_1\infty/\ h_1 g\ \rho_s+P\ )(\ m_{out}\infty/m_{outmax})\upsilon_1$

$-1/2\ m_{out}\infty\ (P\infty/\ h_1 g\ \rho_s+P)\ P' -3/2 m_{ol}\infty\ /m\ \upsilon_3]$

or $\mathbf{T_{fbl} d\upsilon_1/dt=[\ \mu_1 -(w_1 K_{1v1}+w_{2K2v1})\ \mu_1 - (w_1 K_1\ \rho+w_2 K_2 \rho) P' -3/2 w_{31}\ \upsilon_3]}$ [12]

Considering that $h_1=h_0+h_3$; we have $\Delta h_1=\Delta h_3=1$, so $\upsilon_3= (h_1\infty/h_3\infty)\ \upsilon_1$ or $a_{13}\ \upsilon_1$, Equation 12 can be written as

$T_{fb1} d\upsilon_1/dt=[\ \mu_1 -(w_1 K_{1v1}+K_{2v1})\ \mu_1 - (w_1 K_1 \rho+w_2 K_2 \rho) P' -3/2 w_{31}\ a_{13}\ \upsilon_1]$

Or$\mathbf{T_{fbl}} d\upsilon_1/dt+A\,\upsilon_1= \mu_1 \mathbf{-BP'}$ [13]

2.2 Material balance for overflow system:

$dm_{ch}/dt=[m_{ol1}-m_{ol2}]$

or $m_{ch}=A_{ch}h_{ch}\rho_s=V_{ch}\rho_s$

$d\Delta m_{ch}/dt=\Delta m_{ol}-\Delta m_{ol2}$ [14]

$\Delta m_{ch}= A_{ch}h_{ch}\infty\, \rho_s\ \upsilon_2$ or Flow of stock, $m_{ol2}=A_{op}C_{d4}\sqrt{2\rho s(h_{ch}\ \rho_s g+P)}$.

$\Delta m_{ol2}=1/2\ m_{ol2}\infty\ \rho_s g(h_{ch}\infty\ /\ h_{ch}\ g\ \ \rho_s+P\ )\ \upsilon_2+1/2\ m_{ol2}\infty(P\infty/\ h_{ch} g\ \rho_s+P)\ P'$ [15]

Substituting the values of Δm_{ol}, Δm_{ol2} & Δm_{ch} into [14].

$d(V_2\ \rho_s\ \upsilon_2)/dt= 3/2 m_{ol}\infty\,\upsilon_3 -1/2\ m_{ol2}\infty\,(P\infty/ h_2 g\ \rho_s+P)\ P' -1/2\ m_{ol2}\infty\rho_s g(h_{ol}\infty/\ h_{ol} g\ \rho_s+P\ )\ \upsilon_2$

or $V_2\ \rho s(d\upsilon_2/dt) = 3/2 m_{ol}\infty a_{13}\upsilon_1 -1/2\ m_{ol2}\infty\ (P\infty/\ h_{ch} g\ \rho_s+P)\ P' -1/2\ m_{ol2}\infty\rho_s g(h_{ch}\infty/\ h_{ch} g\ \rho_s+P\ )\ \upsilon_2$

or $(V_2\ \rho s/\ m_{ol2}\infty\ )\rho_s\ \ (d\upsilon_2/dt)\ =\ [3/2 m_{ol}\infty\ a_{13}\upsilon_1\ -1/2\ m_{ol2}\infty\ \ (P\infty\ /\ h_{ch} g\ \ \rho_s+P)\ \ P' -1/2\ m_{ol2}\infty\rho_s g(h_{ch}\infty/\ h_{ch} g\ \ \rho_s+P\ )\ \upsilon_2]/\ m_{ol2}\infty$

or $T_{fblo}\ d\upsilon_2/dt =w_{21}\ \upsilon_1 -K_3\rho P' -K_{1v2}\ \upsilon_2$;

or $\mathbf{T_{fblo} d\upsilon_2/dt+K_{1v2}\upsilon_2=w_{21}\upsilon_1 -K_3}\rho P'$ **[16]**

2.3 Material balance for air cushion:

$m_{air}=m_{sup}-m_{rem}$

or $d\Delta m_{air}/dt=\Delta m_{sup}-\Delta m_{rem}$ [17]

$m_{air}=V_3\ \rho_a$ [18]

$V_3=V_o-V_1-V_2$ [19]

$\Delta m_{air}=\rho_a\infty\Delta V_3+V_3\infty\Delta\rho_a$ [20]

Putting the value of V_3 in equation[20], then

$\Delta m_{air}=\rho_a\infty(\Delta V_1 -\Delta V2)+V_3\infty\rho_a\Delta P/P\infty$

or $\Delta m_{air}=-\rho_a\infty\ \ \Delta V_1 -\Delta V_2 \rho_a\infty\ \ +V_3\infty\ \ \rho_a P'$ [21]

Loss of air through valve C_5 & C_6

$m_{sup}=A_{c5}K_5\sqrt{2\rho_a(P_{51}-P_{52})}$;

$m_{rem}=A_{c6}K_6\sqrt{2\rho_a(P_{61}-P_{62})}$

$\Delta m_{sup}=m_{supmax.}(\Delta C_5/C_{5max})-1/2\ m_{sup}\infty.(P_{52}\infty\ /P_{51}-P_{52})P'$ if valve C_5 is linear.

$\Delta m_{sup}=m_{supmax.}\mu_5 -1/2\ \ m_{sup}\infty\ \ .(P_{52}\infty\ \ /P_{51}- P_{52})P'\Delta m_{rem}=m_{remmax.}(\Delta C_6/C_{6max})-1/2 m_{rem}\infty.(P_{61}\infty/P_{61}-P_{62})P'$

Or $\Delta m_{rem}=m_{remmax.}\mu_6 -1/2 m_{rem}\infty\ .(P_{61}\infty\ /P_{61}- P_{62})P'$ [22]

C_6 is constant, so $\mu_6=0$;

$\Delta m_{rem}= -1/2\ m_{rem}\infty.\ (P_{61}\infty/P_{61}-P_{62})P'$ [23]

Putting the values of Δm_{air}, Δm_{sup} , Δm_{rem} in equation [5.22], we get

$d/dt(\rho_a\infty\ \Delta v_3+v_3\infty\ \Delta\rho_a)=\ m_{supmax.}\ \ \mu_5 -(1/2\ m_{sup}\infty.\ (P_{52}\infty/P_{51}-P_{52} -1/2\ m_{rem}\infty.\ (P_{61}\infty/P_{61}- P_{62})P'$

Or $d/dt(-\Delta v_1\ \ \rho_a\infty\ -\Delta v_2\ \ \rho_a\infty\ +\ v_3\ \ \rho_a P')= m_{supmax.}\ \ \mu_5 -(1/2\ \ m_{sup}\infty\ .\ \ (P_{52}\infty\ /P_{51}-P_{52} -1/2\ m_{rem}\infty.\ (P_{61}\infty/P_{61}-P_{62})P'$

$\mathbf{T_{air} dP'/dt=w_4(k_4+k_5)P'= \mu_5+T_{tv1} d_{u1}/dt+ T_{tv2}\ du_2/dt}$ [24]

Dynamic process in the flow box under examination may be properly understood with the help of equations**(Mardon)**

$T_{fbl} du_1/dt +Au_1= \mu_1 -BP'$;

$T_{fblo} du_2/dt +k_{1v2}\ u_2=w_{21}u_1 k_{3\rho}P'$;

$T_{air} dP'/dt+w_4(k_4+k_5)P'=\ \mu_5+\ T_{tv1}\ \ d_{u1}/dt+ T_{tv2}\ du_2/dt$

These equations may be represented in the following form

$\mathbf{T_{fbl} du_1/dt +Au_1= \mu_1 -BP'}$ [25]

$\mathbf{T_{fblo} du_2/dt +C\ u_2=Eu_1 DP'}$ [26]

$\mathbf{T_{air} dP'/dt+F\ \ P'=\ \ \mu_5+\ \ T_{tv1}\ \ d_{u1}/dt+\ \ T_{tv2}\ du_2/dt}$ [27]

In order to determine the transition process as originating irregulating channel of flow box. It is necessary to solve the set of equation w.r.to P' and u. The equation can be written as

$(T_{fbl}s +A)u_1= \mu_1 -BP'$

Or $u_1= \mu_1/\ (T_{fbl}s +A)\ \ BP'/(T_{fbl}s +A)$

If $Q=1/(T_{fbl}s+A)$; $R=B'/(T_{fbl}s+A)$,

or **Then** $\mathbf{u_1=Q\mu_1 -RP'}$ **[28]**

Equation[5.27] can be written as

$(T_{air}s+F)P'= \mu_5+T_{tv1}du_1/dt+T_{tv2}du_2/dt$

From equation[5.26]

$(T_{fblo}s +C)u_2=Eu_1 DP'$

Or $[(T_{fblo}\ \ s\ \ +C)(T_{tv2}s)]=\ \ (T_{tv2}sE)u_1\ (T_{tv2}sD)P'$ [29]

From equation [5.27]

$(T_{tv2}s)u_2=(T_{tv1}s)u_1 -(T_{air}s+F)P'+ \mu_5$

Or $[(T_{fblo}\ s\ +C)\ (T_{tv2}s)]u_2=[(T_{fblo}\ s\ +C)\ (T_{tv1})]u_1 -\ \ [(T_{air}s+F)\ \ (T_{fblo}\ \ s\ \ +C)]P'+ \mu_5(T_{fblo}s +C)]$ [30]

Subtracting equation [30] from [29]

$[T_{tv2}sE-(T_{fblo}\ \ s\ \ +C)\ \ (T_{tv2}s)]u_1 -[T_{tv2}sD- (T_{air}s+F)\ (T_{fblo}s +C)]P'+ \mu_5(T_{fblo}s +C)$

or $P'=[\ T_{tv2}sE+-(T_{fblo}\ s\ +C)\ (T_{tv1}s)]u_1/[T_{air}T_{fblo}s^2+(T_{air}C+T_{tv2}D+T_{fblo}F)\ s+FC]$

$+\ \mu_5(T_{fblo}\ \ s\ \ +C)/\ \ [T_{air}T_{fblo}s^2 +(T_{air}C+T_{tv2}D+T_{fblo}F)s+FC]$ [31]

Then equations can be written as

$\mathbf{P'=xu_1+y\,\mu_5}$ **[32]**

$\mathbf{U_1=Q\,\mu_1 -RP'}$ **[33]**

From equations [32 & 33], both values u_1 & P' are related with process conditions. Variable opening of valves μ_1 or μ_5 affect regulation in the valve of these variables. Because they are related with the relationship**(mardon)**

$\mathbf{V_1=Q'(s)\,\mu_1+R'(s)\,\mu_5}$ **[34]**

$\mathbf{\rho_1=x'(s)\,\mu_1+Y'(s)\,\mu_5}$ **[35]**

Simulation results:

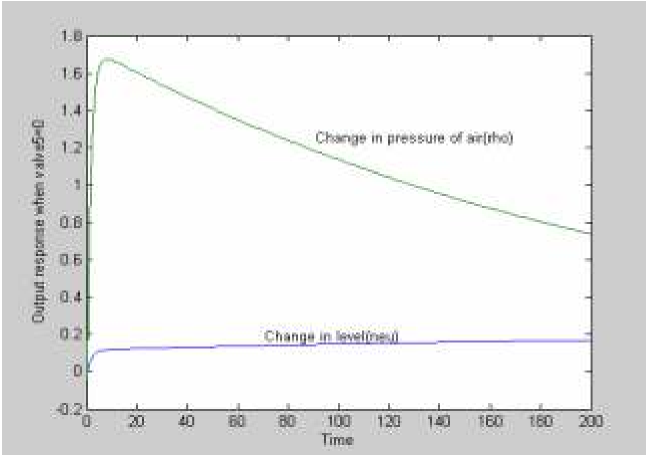
The simulation results of equations 34 & 35 are shown in figs.2 , 3, 6,& 7, closed loop control system has also been designed with the help of maltab software, when $\mu_1=0$, $\mu_5=0$.

3.Development of ANN controller for the case of air pressure and level in the headbox:

For the case of air pressure(rho, ρ) and level(neu/neo, V) ,design the ANN controller with following ANN parameters are as shown in table 1 . The training programmes for the same is also developed.

4.Comparison of simulated data between PID and ANN controller:

After simulating the process, data is used for training the network, the tables 2 &3 show the statistical data and errors between PID and ANN data. The plots show the errors between PID and ANN data with a given set point. Both the controllers show over damped system. Statistical data are also depicted in



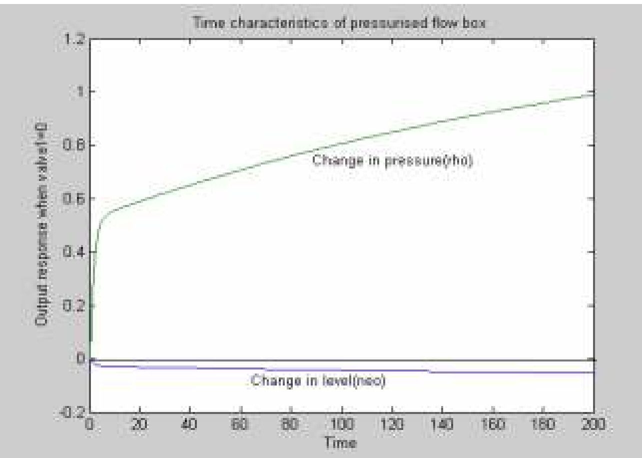


Fig.-2 Characteristics of pressurized flow box when μ_5=0,

Fig.-3 Characteristics of pressurized flow box when μ_1=0,

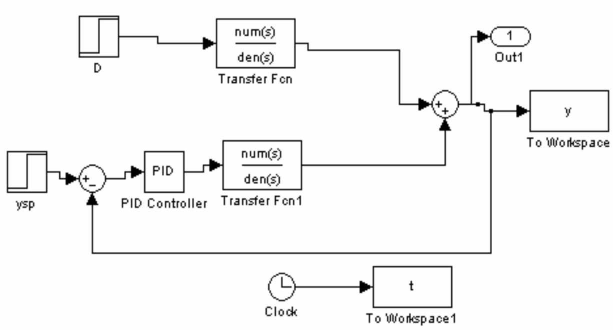


Fig. 4 Closed loop system for V_1, when μ_5=0

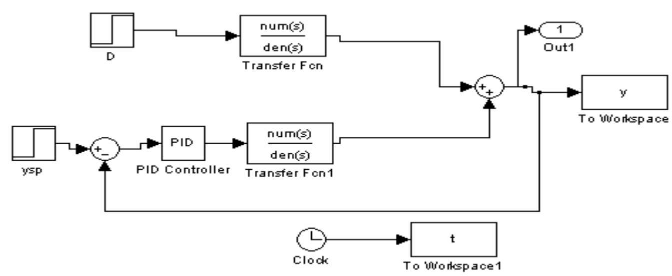
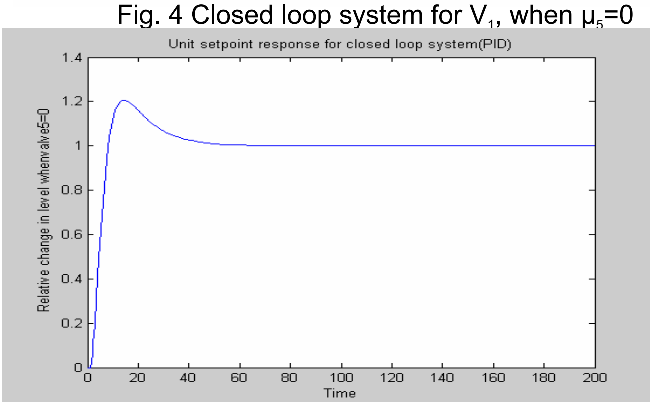


Fig.-5 Closed loop system for ρ_1, when μ_5=0



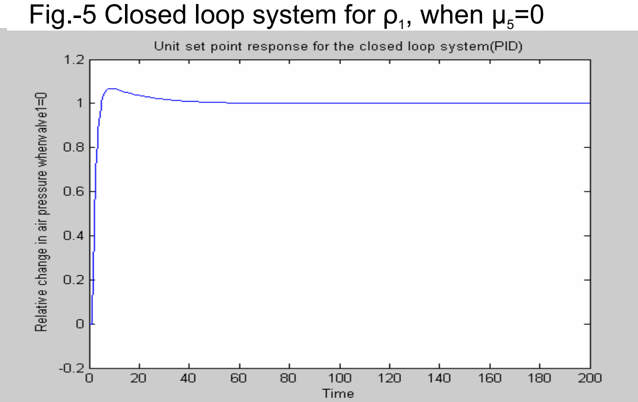
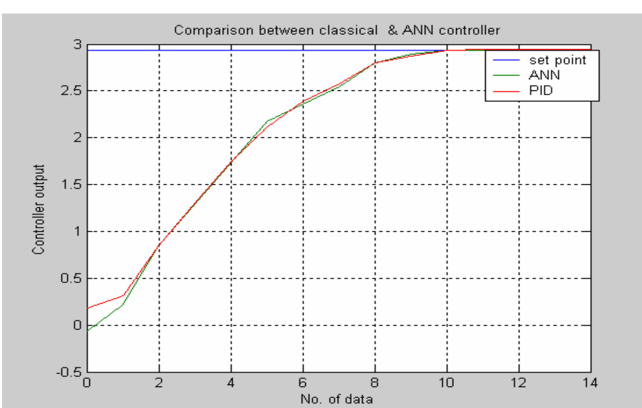


Fig.-6 Unit set point response for closed loop system for V_1, when μ_5=0

Fig.-7 Unit set point response for closed loop system for ρ_1, when μ_5=0



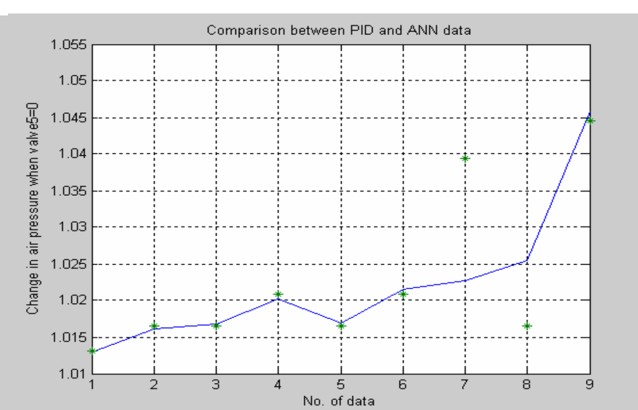


Fig.-8 Comparison between classical and ANN data for V_1, when μ_5=0

Fig.-9 Comparison between classical and ANN data for ρ_1, when μ_5=0

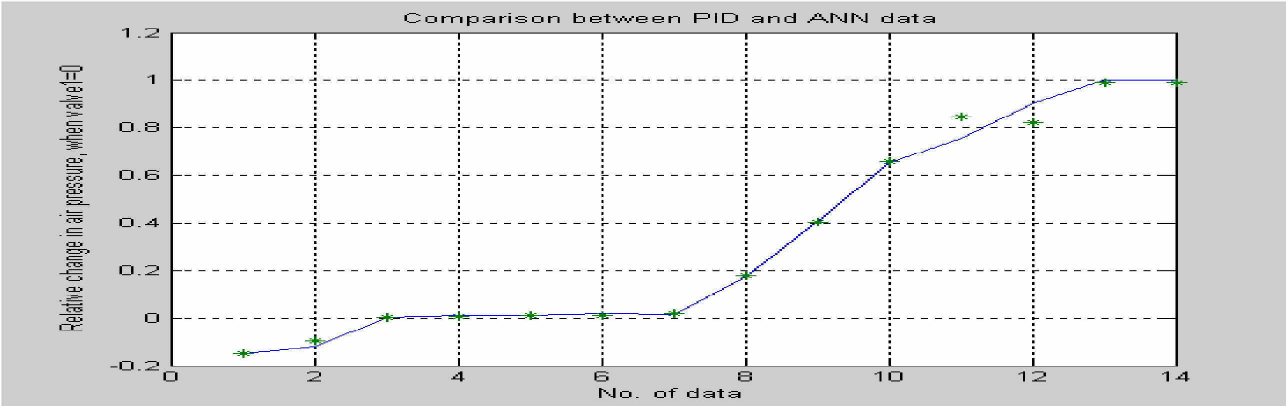


Fig.-10 Comparison between classical and ANN data for ρ_2, when μ_1=0

TABLE: 1

Parameters	V_1	ρ_1	P_2
Input nodes	2	2	2
Hidden nodes	5	5	5
Output nodes	1	1	1
Activation function	Tansig	tansig	Tansig
Algorithm	Gradient descent	Gradient descent	Gradient descent

TABLE:2 COMPARISON BETWEEN PID CONTROLLER FOR V, ρ

Specifications	**PID value for (V)**	**PID value for(ρ)**
Max. overshoot	22.7%	6.8%
Delay time	5.4 sec.	2.14 sec.
Min.	0	0
Max.	1.227	1.068
Mean	.5174	.8179
Median	.4415	1
Std.	.5122	.3852

TABLE:3

V_1	**Min. error**	-.0551
	Max. error	.0852
	Average error	.0242
ρ_1		
	Min. error	-.0009
	Max. error	.0165
	Average error	.0038
ρ_2		
	Min. error	-.0912
	Max. error	.082
	Average error	-.0008

tables. Which show that the ANN controller gives approximately the same value as the conventional controller provides.

5.Conclusions:

To demonstrate the effectiveness of the design procedure presented herein, a model of a paper making machine headbox was considered. The objective of the study was to improve regulation with compensatory increases or reductions in stock level with no overshoot condition. The comparison between PID and ANN is more clearly shown in figs. It is found that except two values of ANN other tally very closely. Therefore it can be concluded that that the ANN controller can be used for MIMO system successfully.

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Model of pressurised headbox:

m_{fb}=Amount of stock present in the flow box
m_{in}=Amount of incoming stock
m_{out}=Amount of outgoing stock
m_{ol}=Stock flow through the overflow line
t=time
A_{fb}=Average cross-section area of flow box
h_1=hydrostatic pressure
ρ_s=Density of suspension
ρ_a=Density of air
υ_1=Relative deviation of level
P=Air pressure
H=Height of stock to the axis of valve
μ_1=Relative change in the opening of inlet valve
A_c=Cross section of valve opening
C_{d1}=Discharge coefficient
C_1=Inlet valve
P_{11}=Pressure before entering valveC_1
P_{12}=Pressure after valve C_1
P'=Relative change in pressure of air
C_2=Slice opening
A_{lip}=Cross-sectional area of lip opening
C_{d2}=Discharge coefficient
C_{d3}=Discharge coefficient
b=Width of air flow
h_3=Height of overflow
T_{fbl}=Time constt. For flow flow box for level of stock in the box
w_1, w_2, w_3 =load factors
$K_{1v1}, K_{2v1}, K_{1\rho}, K_{2\rho}, K_{1v2}, K_{3\rho}$=Constant factors depending on the speed of the machine
m_{ch}= Amount of stock present in the channel
m_2= Flow of stock
A_{ch}= Average area of cross-sectional of the channel
h_{ch}= Height of stock level in channel
V_{ch}=Volume of channel
A_{op}=Cross-sectional area of outlet pipe
T_{fblo}=Time constt. For flow box stock level in the overflow pipe
w_{21}=Factor depending on υ_1
m_{air}= Amount of air present above the stock level in the flow box
m_{sup}, m_{rem}=Amount of air supplied and removed from the flow box
V_3=volume of air above stock level in the flow box
A_{c5}, A_{c6}=Cross-sectional area of overflow valves C_5, C_6
K_5, K_6=loss factors
P_{51}, P_{52}=Inlet & Outlet pressure of valve C_5
P_{61}, P_{62}=Inlet & Outlet pressure of valve C_6
T_{air}=Time constt. Of flow box for air cushion
w_4=Load factor
T_{tv1}, T_{tv2}=Time constt. For turbulence in the channel depending on υ_1, υ_2