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TUNING PID CONTROLLER FOR A TEXTILE WEB TENSION CONTROL SYSTEM USING PARTICLE SWARM OPTIMIZATION TECHNIQUE

استخدام طريقة جديدة لضبط ثوابت لمتحكم تناسبي تكاملي تفاضلي (PID) للتحكم في درجة شد القماش باستخدام تقنية إيجاد الحل الأمثل بطريقة حشد الجزيئات (PSO)

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الملخص:

يقدم هذا البحث طريقة جديدة لضبط ثوابت لمتحكم تناسبي تكاملي تفاضلي (PID) للتحكم في درجة شد القماش باستخدام تقنية إيجاد الحل الأمثل بطريقة حشد الجزيئات (PSO). أثبت المتحكم المقترح متانته و تم اختباره من خلال تغيير ثوابت النظام و قيم السمك و العرض المختلفين للأقمشة و التي تم التعبير عنه بمساحة مقطع القماش. و أظهرت نتائج المحاكاة أن تطبيق هذا المتحكم قد حقق أداء جيدا حتى في وجود تغيرات كبيرة في مساحة مقطع القماش. تم إجراء دراسة مقارنة بين المتحكم المقترح و متحكم أخر مبنى على طريقة ال PID تقليدي. وقد أظهرت النتائج أن المتحكم الجديد ذو أداء أفضل.

ABSTRACT:

In this paper, a new method for tuning the parameters of PID controller for Textile Web Tension Control (TWTC) using Particle Swarm Optimization (PSO) technique is presented. The robustness of the proposed controller is investigated through parameter variations and changing the textile web cross-section area. The simulation results show that the applied PSO-based PID controller has achieved good performance even in wide range of cross-section area. A comparative study is made between a traditional PID controller and the proposed one. The performance is shown to be better in case of the PSO-based PID controller.

Kew words: Textile Web Tension Control, PID control, Particle Swarm Optimization.

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1. INTRODUCTION:

In many web-handling plants, an attempt is made to control web tension in a span by controlling the difference between the velocities of rollers at the end of the span. This open-loop tension control is termed "draw control". Open-loop control cannot result in an accurate tension control in a span if tension disturbances occur upstream of that span. That is, a tension disturbance will propagate downstream due to tension transfer.

Kai Jin [1], mentioned in his M.Sc. Thesis titled "Robust Tension Control in Papermaking" that he designed a Model Reference Adaptive Controller far better than industrial tradition PID Control.

He mentioned that his system could be used in textile web and other web form material.

A controller used to regulate the tension in the process must have some robustness to operate under varying condition. The controller must be robust for modeling errors, disturbances, non-linearities and varying plant dynamics, which unavoidable in any control applications [1].

In all textiles processing web tension is a big concern. Starting from carding machine till finishing stenter passing by weaving fabric and fabric dyeing. Web tension control and web speed control.

Many modeling and simulation system have been introduced. It is now an essential to control the web tension in any textile process from the starting of the process till the end of the entire process. Problem comes from the dynamically changing diameter of the winder. Changing speed and tension for all various types of fabrics.

Sakamoto[2] mentioned that in a web or textile processing machine, it is important to maintain the tension of the web between the consecutive pairs of drive rolls so that it does not crease nor cause a web break.

Wei[3] has mentioned that it is necessary to maintain correct tension in the material of most winding machine. It is obvious that when tension is too small, this would lead to softening of the material, and on the other hand excessive tension leads the material to over expansion, deformation and even breaking. Also it is known that lower transport speed reduces the productivity, whereas higher transport speed causes unstable tension and therefore complicates the control mechanism

Osinski[4] mentioned that, there is a need to consider continuous parameter changes such as increasing roll diameter, inertia grow and tension variation. He divided the common type of web winder into three types, and these are: center-driven web winder, surface web winders and turret winders. Also he indicates that the most important part in the process is measuring of the tension. And there are two types one direct and the second is indirect. The direct one will be via Load Cells. While the indirect one is via dancer rollers.

Benlatreche[5], reported that in order to control web tension over the entire production line requires decoupling between web tension and speed, so that a constant tension can be maintained during speed changes. He also added that, robustness with respect to web elasticity variation is another important requirement. He mentioned that achieving robustness will not only provide a safe control of the web throughout the whole industrial process, but also it will permit to use the same controller for different types of web.

So far, many industrial web-transport systems have used decentralized PI-type controllers. However, for higher control requirements more efficient control strategies must be used.

PSO is a new technique for nonlinear optimization. It has the advantages of being a very simple concept and computation requirements. PSO is a population based optimization algorithm that is motivated from the simulation of social behavior. Each individual in PSO flies in the search space with a velocity that is dynamically adjusted according to its own flying experience and its companions' flying experience. Compared with other evolutionary algorithms, such as Genetic Algorithms (GAs), the PSO algorithm possesses some attractive properties such as memory and constructive cooperation between individuals, so it has more chance to "fly" into better solution areas more quickly [6].

A new robust web tension PSO-based PID controller to optimize the controller parameters is presented in this paper. The proposed PID controller guarantees the stability of web system for a wide range of Textile Web Cross-Sectional Area. The web system performance is shown to be better with the proposed controller given in this paper.

2. WEB TRANSPORT SYSTEM MODEL

In this section, a "unified" closed-loop dynamic model will be derived for the system which includes a dancer represented by the middle roll as shown in Figure (1). This model will be evaluated for a typical web material and typical web transport system operating conditions. The following assumptions were made in the derivation of the unified model:

1. The length of contact region between the web material and roller is negligible Compared to the length of span between the rollers.

2. The thickness of the web is very small compared with the radius of rollers over which the web is wrapped.

3. There is no slippage between the web material and the rollers.

4. There is no mass transfer between the web material and the environment.

5. The strain in the web is small.

6. The strain is uniform within the web span.

7. The web cross-section in the unstretched state does not vary along the web.

8. The density and the modulus of elasticity of the web in the unstretched state are constant over the cross-section.

9. The web is perfectly elastic.

10. The web material is isotropic, so the machine direction stress prevails.

11. The web properties do not change with temperature or humidity.

The unified mathematical model [1] was developed for the System of tension control by changing of speed of driven roller by controlling the DC motors which is very popular in industry. The multi-span web system modeled for this work is a common simplification of typical multi-span systems, as shown in Figure (1).

Motors are used to change the tangential velocities of the rollers in order to control the web tension in each processing section. U_n denotes the change in the input to the n-th driving motor, V_n denotes the change in the tangential velocity of the n-th driven roller, and T_n denotes the change in the longitudinal tension in the n-th span.

Despite the availability of many different control design techniques, by far the most widely encountered procedure of tension control is that of PID control [1]. The dynamics model for processing section 2 by controlling the velocity of the rollers is given from Eqs. (1) and (2):

$$\frac{dT_2}{dt} = -\frac{v_{20}}{L_2}T_2 + \frac{v_{10}}{L_2}T_1 + \frac{AE}{L_2}(V_2 - V_1) \qquad (1)$$

$$\frac{dV_2}{dt} = -\frac{B_{f2}}{J_2}V_2 + \frac{R_2^2}{J_2}(T_3 - T_2) + \frac{R_2}{J_2}K_2U_2 \qquad (2)$$

Where

B_f = Rotary friction constant of bearing

J_n = Polar moment of inertia of roll
K_n = Motor constant
A = Cross-sectional area of web
E = Young's modulus
v_{∞} = Initial tangential velocity of n-th roller
V_n = Change of velocity of n-th driven roller
T_n = Change of tension in n-th section
L_n = Length of n-th span
R_n = Radius of roller
U_n = Change in input to the motor driving the roller
Synthesis is done in state-space form using the state

The dynamic equations of this model can be rewritten in the state-space form as

$$\dot{x}_2(t)=A_2x_2(t)+A_{21}x_1(t)+A_{23}x_3(t)+B_2u_2(t) \tag{3}$$

Where the state-space matrices are given by

$$X_2(t) = [\Delta T_2(t), \Delta V_2]^T, \tag{4}$$

$$A_2=\begin{bmatrix} -\frac{v_{20}}{L_2} & \frac{AE}{L_2} \\ -\frac{R_2^2}{J_2} & -\frac{B_{f2}}{J_2} \end{bmatrix} \tag{5}$$

$$B_2=\begin{bmatrix} 0 \\ \frac{R_2K_2}{J_2} \end{bmatrix} \tag{6}$$

$$C_2 = [1\ 0] \tag{7}$$

$$A_{21}=\begin{bmatrix} \frac{v_{10}}{L_2} & -\frac{AE}{L_2} \\ 0 & 0 \end{bmatrix} \tag{8}$$

$$A_{23}=\begin{bmatrix} 0 & 0 \\ \frac{R_2^2}{J_2} & 0 \end{bmatrix} \tag{9}$$

For simplicity, it was assumed that the nominal plants are free of the downstream and upstream disturbances, that is, $T_1=V_1=T_3=0$.

3- BASIC METHOD OF PSO:

Kennedy and Eberhart developed a PSO concept [7]. The PSO is basically developed through simulation of bird flocking in two-dimensional space. The position of each agent is represented by XY axis position and also the velocity is expressed by v_x and v_y in the x and y direction respectively. Modification of the agent position is realized by the position and velocity information.

Bird flocking optimizes a certain objective function. Each agent knows its best value so far (pbest), and its xy position. This information is analogous to the personal experience of each agent. Moreover, each agent knows the best value so far in the group (gbest) among the obtained pbests. This information is analogous to knowledge of how other agents in the group have performed. Namely, each agent tries to modify its position. Position modification can be represented by the concept of velocity. The velocity of each agent can be modified by the following equation [7]:

$$v_i^{k+1} = K[v_i^k + c_1 rand_1 * (pbest_i - s_i^k) + c_2 rand_2 * (gbest - s_i^k)] \qquad (10)$$

where $K = the\ constriction\ factor = \dfrac{2}{\left|2-\varphi-\sqrt{\varphi^2-4\varphi}\right|}$, $and \quad \varphi = c_1 + c_2, \varphi > 4$

v_i^k : velocity of agent i at iteration k,
c_j : weighting factor,
$rand_j$: random number between 0 and 1,
s_i^k : current position of agent i at iteration k,
$pbest_i$: pbest of agent i,
$gbest$: gbest of the group.

The current position (searching point in the solution space) can be modified by the following equation:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \qquad (11)$$

4- COMPUTER SIMULATION

4.1 Study system

To account for the uncertainty in parameters and to allow for changes in operating conditions, the study system is represented by three models having different parameters. Model A represents the design point for the two controllers under study. Models B, and C represent a change in Model A parameters by ±50% for T_p and T_t, T_g, and R by ±30%. All these parameters are listed in Table 1.

4.2 Design of PSO-based PID controller

In the single area system shown in Fig. 1, the conventional integral controller is replaced by a PID controller with the following structure:

$$G_c(s) = kk + \frac{k_I}{s} + k_d s \qquad (12)$$

where
kk = proportional control gain
ki = integral control gain
& k_d = differential control gain.

A Particle Swarm Optimization Toolbox (PSOt) for use with the Matlab scientific programming environment has been developed in [8]. It is modified and employed to get the optimal values of parameters according to the given predefined ranges. In addition to the main PSO program, additional programs were designed to get the state-space representation of the system.

4.3 Objective function

To increase the system damping, the eigenvalue-based objective function is considered as follows:

$$J = \min\{\varsigma_i\} \qquad (13)$$

where ς_i is the damping ratio of the ith electromechanical mode eigenvalue. In the optimization process, it is aimed to maximize J in order to increase the damping of the poorly damped electromechanical modes. The optimization problem can be formulated as follows:

Maximize (J) subject to

$$kk^{\min} \le kk \le kk^{\max}$$
$$k_I^{\min} \le k_I \le k_I^{\max}$$
$$k_d^{\min} \le k_d \le k_d^{\max}$$

(14)

Typical ranges of the optimized parameters are [0: 10] for all gains. The system A matrix after adding the PID signals becomes:

$$A = \begin{bmatrix} -\frac{v_{20}}{L_2} & \frac{AE}{L_2} & 0 \\ 0 & -\frac{B_{f2}}{J_2} & \frac{R_2}{J_2} \\ k_1 & k_2 & \frac{R_2}{J_2} \end{bmatrix}$$

(15)

Where:

$$k_1 = [R_2 + K_p - \frac{K_I L_2}{v_{20}}] - \frac{k_d {v_{20}}^2}{L^2{}_2}$$

(16)

$$k_2 = [\frac{K_d v_{20}}{L_2} - R_2 - K_p + \frac{k_d B_{f2}}{J_2}]$$

(17)

The obtained values of the PID gains using PSO are: kk = 1.2987, k_I = 0.2113, k_d = 0.6780;

4.4 Comparative study

The reliability of the proposed PSO-based PID controller is evaluated through a comparison of its response with that of the traditional PID controller developed in [1]. In order to inspect their robustness, the two controllers are applied to different cross-sectional area of the web higher and lower from the designed value. The applied case studies are listed in Table (2).

5- SIMULATION RESULTS

The simulation results are illustrated in seven figures (Figure 2-8). Each figure represents a case study showing the responses of the Motor velocity with the two considered controllers. The qualitative analysis of the obtained results may lead to the following conclusions:

Figure (2) shows an example how self-tuning controller can improve process performance. The system becomes stable in less than 5seconds.

In figure (3), the same is applied for cross-sectional area of 0.06, but lesser time. This shows that the system is robust against change in cross-sectional area of the web.

In figure (4) and (5), A third and fourth simualtion were executed on a web cross-section = 0.12 and 0.15 consequently, and again the system was showing robustiness against any change in web cross-section.

In figure (6) a web cross-section =0.18 was applied to the simulation system and the traditional PID become un-stable while the proposed swarm-based PID controlles still robust and acting well and fast against such change in the area of the web cross-section.

In figure (7) and (8), web cross-section equal to A=0.24 and A=0.35, the swarm-based PID controller still robust and working well without any oscillation.

6- CONCLUSION

- In this paper, a new PID controller using PSO technique is applied to textile web tension system like knitted fabric compactor or any other textile web. The controller uses the tension deviation of the system as a single feedback signal.
- The robustness of the proposed controller is investigated through parameter variations and changing the area of the textile web cross-section.
- The proposed controller exhibits better performance in all case studies under consideration.

An extra and important advantage of the proposed controller is its simple structure.

- We can conclude that the proposed PSO-based PID controller exhibits better transient performance.

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Table 1 Study System Parameters

Parameters	Description	Value
A	Web cross-sectional area	0.12 in^2
E	Material Modulus of Elasticity	3.5* 10^5 lb/in^2
J	Polar moment of Inertia of roll	94 lb in^2
L	Span length	120 in
v_{no}	Initial velocity of the span	1000 ft/min
R	Roller radius	5 in
B_f	Bearing rotary friction constant	0.2

Table (2) List of Applied Case Studies

Case Study	1	2	3	4	5	6	7
Web Cross section Area	0.01	0.06	0.12	0.15	0.18	0.24	0.36

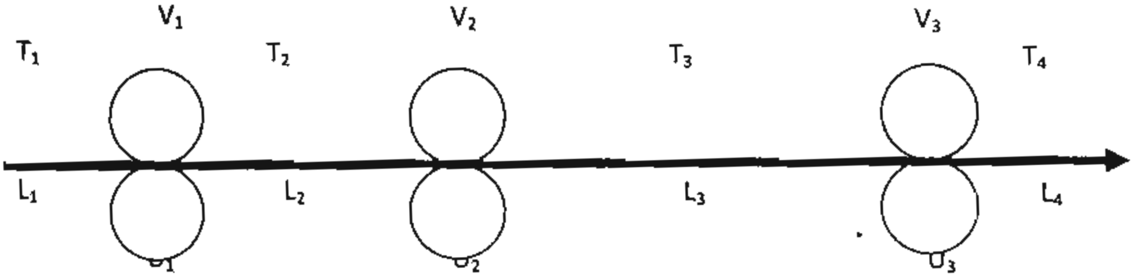

Figure (1) Two – Span Web Transport System

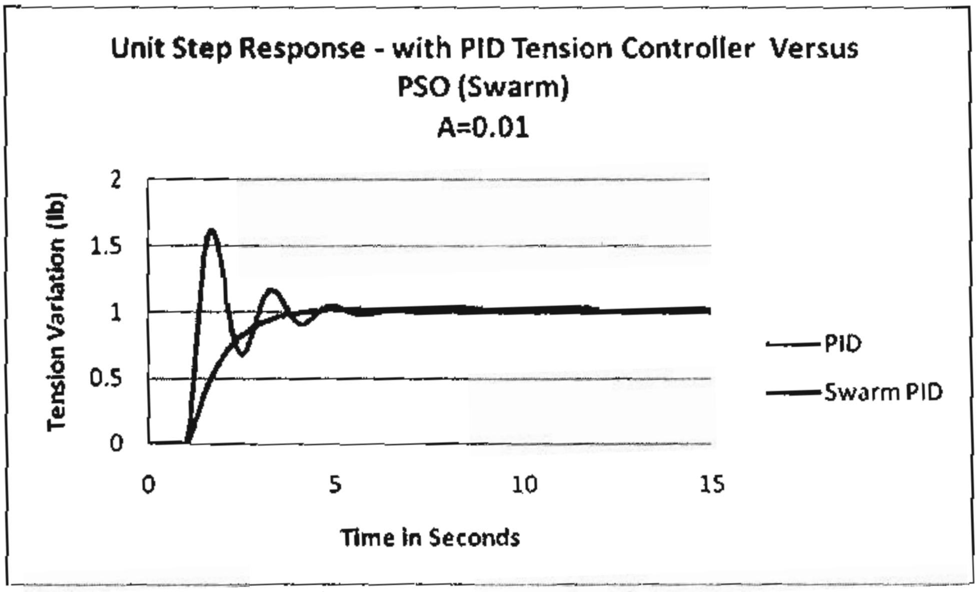

Figure (2) Web Cross –Section Area A= 0.01

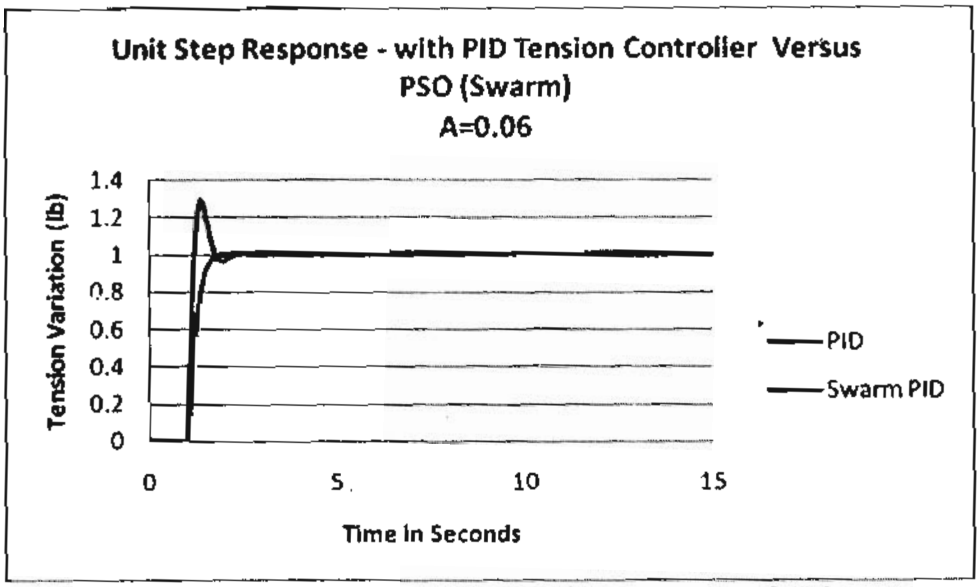

Figure (3) Web Cross –Section Area A= 0.06

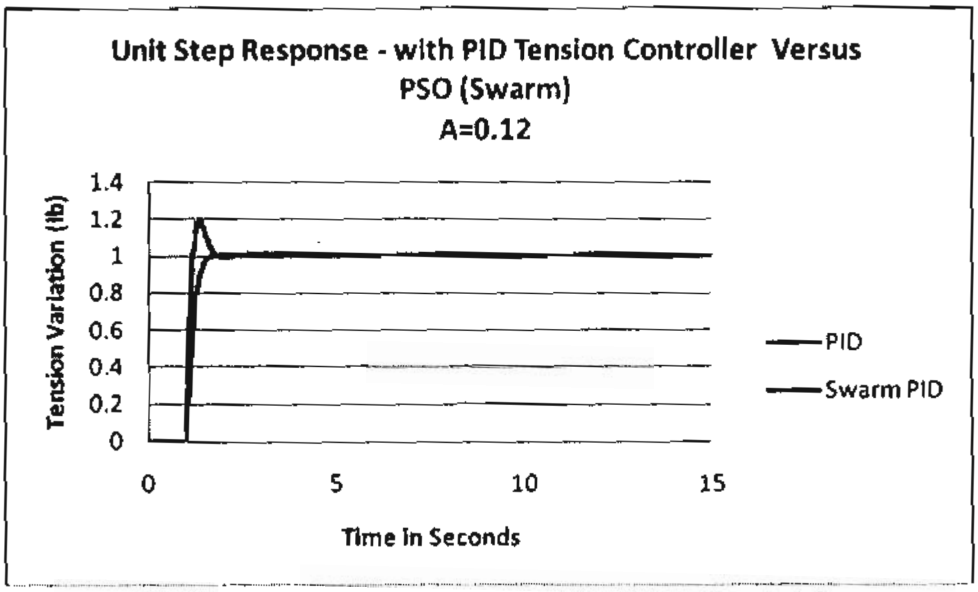

Figure (4) Web Cross –Section Area A= 0.12

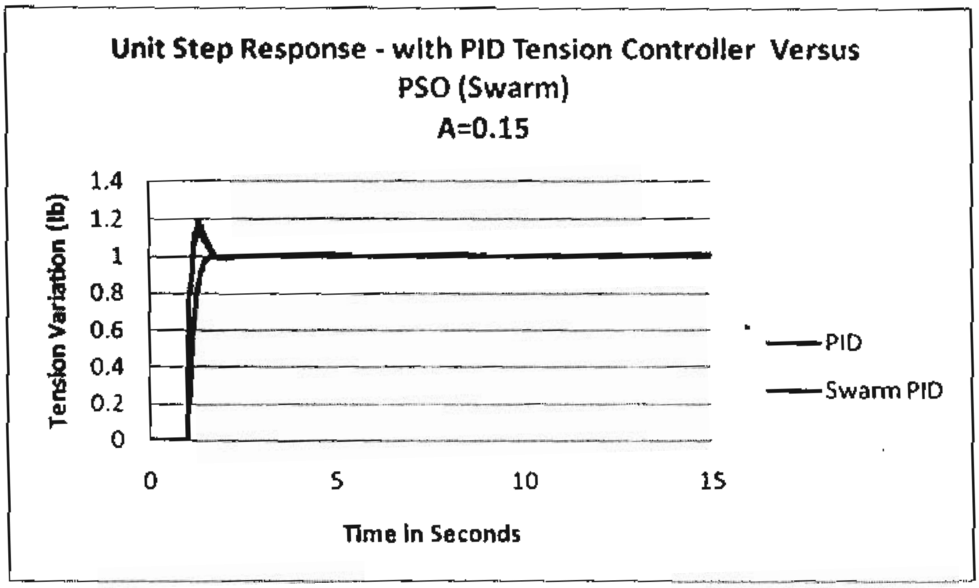

Figure (5) Web Cross –Section Area A= 0.15

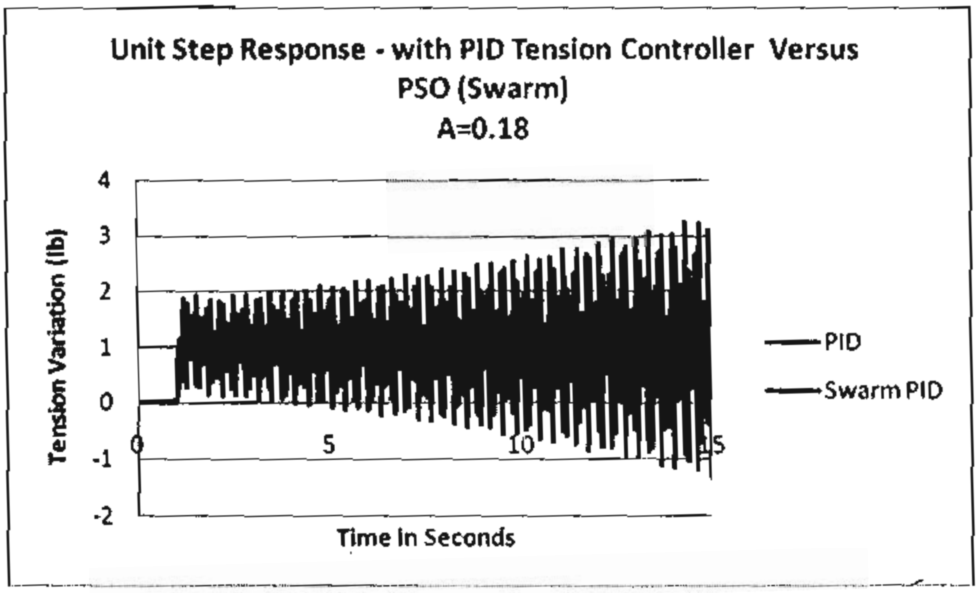

Figure (6) Web Cross –Section Area A= 0.18

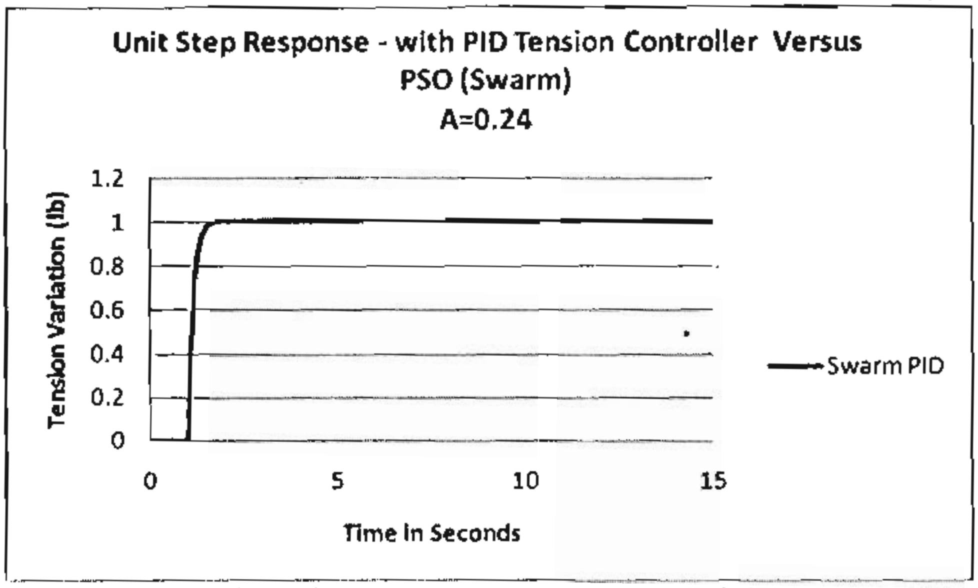

Figure (7) Web Cross –Section Area A= 0.24

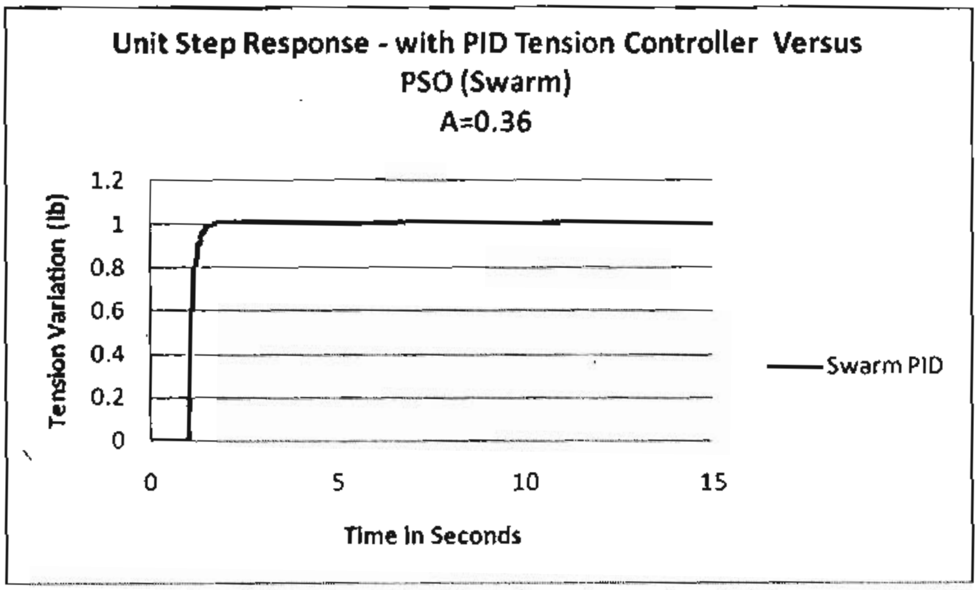

Figure (8) Web Cross –Section Area A= 0.36