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Design & Implementation of Closed Loop PID Mechanism for wire Tension Control (Tensioner) in Winding Machine

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Abstract **-** Wire tensioners form a crucial part of winding equipment. The tensioner is used to deliver the wire by measuring the maximum tension that wire would tolerate. The quality of winding and productivity of winding machines depends on wire tensioners to a large extent. Usually, the tensioners used in winding application are completely manufactured mechanical with no/little electronics in it, which are not compatible and reliable for variable tensions and different diameter of wires. Since these tensioners are not flexible, for winding machines, alternatives based on Digital Signal Processors (DSP) or any appropriate Controllers are used. We are proposing a PIC Controller based tensioner that would deliver a constant tension with closed loop PID control at constant position of dancer arm mainly by using servomotor and stepper motor. This method is economical and easily scalable to any equivalent controller architecture. This work was supported by Synthesis Winding Technologies Pvt. Ltd, Bangalore.

Keywords:*Tensioner, Pulley, Spindle, PID, Wire tensioner, ADC (Analog to digital converter), Bobbin (core on which wire is wounded), MCU (Micro Controller Unit).*

I. INTRODUCTION

Power design is always the main design criteria in any engineering product. The design of coil windings for the Transformer plays a major role in power transform. The tensioners for winding machines must be properly designed to achieve desired ratings of windings in transformer. Tensioner is an accessory part of a coil winding machine that is designed for measure of maximum tension that a wire would tolerate.

The figure 1 shows overview of winding machine [1]. The wire from wire spool is routed via the tensioner's wire router (servomotor) than through a pulley (wire guide) for winding on a spindle. The main function is to make the spindle rotate on which the bobbin (core or former) is mounted for winding the wire to make a coil. The wire is routed through the wire guide pulley of the tensioners' dancer arm and hence the position of the arm is to be controlled for better wire delivery for proper winding. The proper designing of tensioner ensures proper positioning of dancer arm and speed control of servo motor to deliver wire at rated tension to control winding of transformer for stipulated power transform.

Mechanical tensioners are readily used in winding applications. But they are not flexible and scalable as these devices require replacement of entire tensioner for different diameter of wire, which is not only economical but also time consuming [2].

Proposed tensioner card is designed with closed loop tension control for proper deliver of wire to the machine using microcontroller. This tensioner card has features such as Programmable tension settings (possibility of changing wire tension during winding sequence), user friendly controls for wire tension settings; automatic wire breaks detection and simulated tension display using 7-segment display. The PID [3-7] concept is utilized and implemented for dancer arm position control depending on the speed of the servomotor with proper tension. So far for winding applications, the electrical tensioners were imported from other countries, with not much of intelligence and which is not affordable as it is not economical.

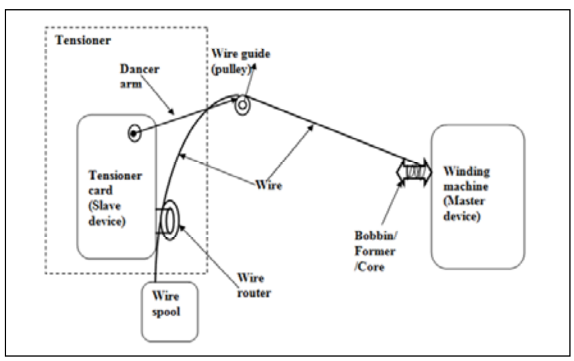

Fig 1: Overview of Winding Machine.

The tensioner card proposed is based on PIC18F4431 microcontroller for performing closed loop control operation. There is spring holding the fulcrum for which the dancer arm is fixed and contraction and expansion of the spring causes the movement of the fulcrum and defines the stiffness of the dancer arm to deliver the tension. This defines the back tension and this is set by the stepper motor by using the keypad for calibrated tension control. The dancer arm would rotate for making an angle of 90° that's limited mechanically. The dancer movement causes the rotary shaft movement on which the rotary sensor is mounted. The rotary sensor is selected such that it would read complete 90° movement and give equivalent voltage.

The microcontroller reads the set position value of dancer arm that is fixed irrespective of tension value and delivers constant tension required and the set position is maintained by using closed loop PID control by reading the actual position from the rotary sensor that is mounted on shaft of the dancer arm when power on and winding goes on. This defines the main tension along with servomotor and makes wire delivery easy and stiff for smooth winding. If the tension varies on winding than the wire diameter on coil would vary and the resultant coil wound characteristics area will change. One such characteristic when area changes is the resistance of produced coil will be different when measured as we know the coils are used in power applications and their behavior differs and may lead waste for the application. Not only resistance many other electrical characteristics would also change if the coil parameter changes. The servomotor along with dancer arm would give main tension control and stepper motor for spring position would give back tension which facility is not available in normal mechanical tensioners. So I would like make a note that designed tensioners are also called as servo tensioner that will be more economical and reliable and also flexible.

II. ANALYSIS

Tensioners are basically designed on different requirements:

- Performance: Good performance with more cost
- Economy: Less cost with better performance
- Mid range: Suitable for better performance and also low cost.

The proposed method is based on implementation of the mid range series of electrical servo-tensioner for implementing PID closed loop concept.

III. FEATURES OF TENSIONER IMPLEMENTED ON MCU:

- Programmable tension settings (possibility of changing wire tension during winding sequence).
- The servo tensioner is designed for controlling the position of pulley so that the wire is constantly supplied to the machine while winding.
- The constant supply of wire at required tension avoids the wire cut at higher speed and hence smoothes winding of the coil.
- Adjusting of the different tension depending on the spring position and hence both the thin wire and thick wire can be wound.

III. DESIGN

A. Block Diagram:

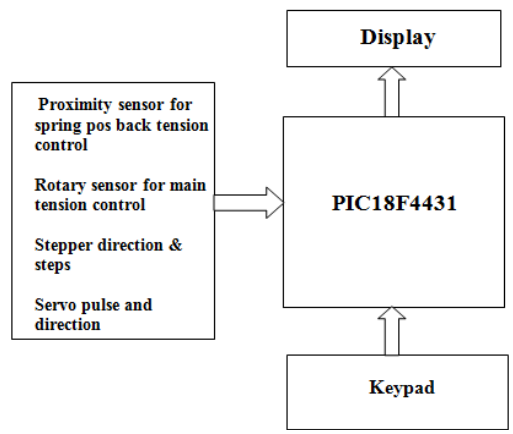

Fig 2: Block diagram of tensioner card

Proximity sensor: The spring position is fixed using stepper motor, where the rotary motion of stepper is converted to linear motion on fulcrum. The initial position of stepper is sensed by *proximity sensor* for reference and the latest spring position value if changed is stored in nonvolatile memory so as to retain the necessary data if power fail happens or during another power on.

Rotary sensor: Mounted on dancer arm's shaft for reading the dancer arm position where angle is linearly proportional to analog voltage as shown in figure below

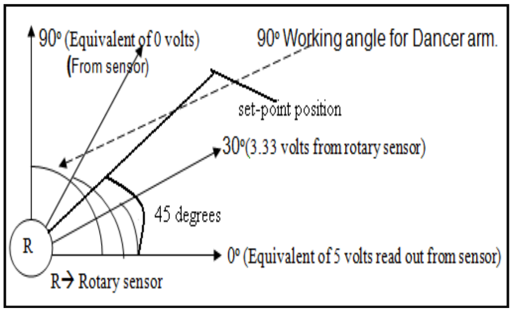

Fig 3: Dancer arm position

Servomotor: PWM controlled mechanism for speed. This is a way of controlling the main tension. The servomotor delivers the wire for winding by controlling the mid position of the dancer arm for constant tension delivery.

The servomotor is operated with speed profile as shown below in figure 4.The initial rise time is given so as to start winding and maintain the constant speed for some time and later decelerate for remaining turns. The purpose of this profile is to make winding smooth and for avoiding wire cut and other irregular errors and similar profile would be followed on main machine where the core is mounted.

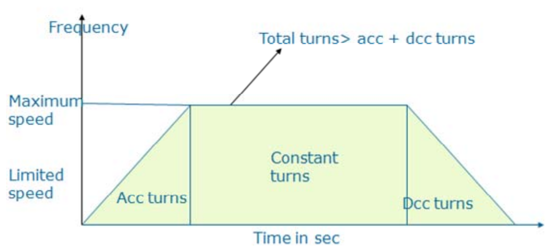

Fig 4: Speed profile for servo motor

The keypad is used to input the tension values online. The system is designed to display the tension values during the winding process.

B. Computation

The PIC controller is used for monitoring the position of the dancer arm and maintains closed loop control. The Controller's processing capabilities will dictate the system's ability to respond to the error and hence PIC controller was used in our slave controller card. The application has two closed loop controls, servomotor feedback and the dancer arm feedback. The arm position is fixed at mid position when winding happens and that point is called the **set-point**. Any deviation from the position is corrected and maintained by PID loop calculations in controller. The coding to fix the dancer arm position is done and gain factors for PID are adjusted depending on the system response for reducing oscillations or vibrations in dancer arm.

The analog voltage from the rotary sesnor is converted to equivalent digital value by using ADC module (10 bit) in PIC for which the PID calculations are done. The dancer arm position is read at higher sampling time so that higher priority is given for PID control compared to other sub functions such as updating 7-segment display and reading keypad. For simplied calculations,

input = 1024 – ADC O/P

The actual position from the rotary sensor read at regular sampling time from ADC, is to be compared from the set point position value specified to find any deviations from set position. The set point value would be equivalent the mid angle(45°) of dancer arm position.

error = input - setpoint

The proportional error got by sampling at regular interval is used for calculating both differential and integral error all and this with gain factor constitutes closed loop PID controller.

W_P, W_d, and W_i refers to a proportional, differential and integral part of the PID control. The gain factors K_P, K_d and K_i are adjusted by practically checking the oscillations (vibrations) on servo motor. The dancer arm position is controlled by the speed of servomotor and feedback for the error is controlled by the rotary sensor mounted on the shaft of dancer arm.

$$W_P = error * K_P$$

The proportional gain (K_P) is multiplied by the error. The amount of correction applied to the system is directly proportional to the error. As the gain increases, the applied correction to the Plant becomes more aggressive. This type of Controller is common for driving the error to a small, but non- zero value, leaving a steady state error. This is the reason for proportional control not being enough in some systems, thereby requiring integral and derivative control to come into play, separately or together.

```
Wi = previous_Wi + test_temp * Ki

if(Wi < negativelimit)
        Wi = negativelimit;

if(Wi > positivelimit)
        Wi = positivelimit;

previous_Wi = Wi;
```

Unlike proportional control, which looks at the present error, integral control looks at past errors. Given this, the accumulative error (sum of all past errors) is used to calculate the integral term, but at fixed time intervals. Basically, every time the fixed interval expires, the current error at that moment is added to the previous_Wi variable.

Wind-up occurs when the accumulative error keeps increasing because the Plant output is saturated. This event can be avoided by setting limits to the accumulative error. It can also be eliminated by not executing the integral term when the Plant output is saturated. Another characteristic is excessive gain that can create an unstable condition within the system, causing it to oscillate. The integral gain must be thoroughly tested for all possible situations to find the best overall value. In conclusion, as the accumulative error increases, the integral term has a greater effect on the Plant. In a sluggish system, this could dominate the value that is sent to the Plant.

Diff = error - previous_error

$$W_d = Diff * K_d$$

previous_error = error

The derivative term makes an adjustment based on the rate at which the plant output is changing from its Set-point. A notable characteristic in this type of control is when the error is constant, or at the maximum limit, the effect is minimal. There are some systems where proportional and/or integral do not provide enough control. In these systems, adding in the derivative term completes the control requirements.

$$V_{out} = W_p + W_d + W_i$$

Once the total error value for servomotor is found the limiting is also to be done for servomotor maximum speed to avoid irregular errors.

```
if(Vout > 80000)  //limit max servo to  5000 RPM
      Vout = 80000;
```

The above equations are involved in calculation of PWM for servomotor for speed control. The PID output is calculated after the proportional, integral and derivative terms have been determined. In addition to this calculation is the pid_sign bit, which the user must check to decide which direction the Plant will be driven. The simulated speed and position profile of main controller is shown below in figure 5 that drives the slave controller designed for tensioner.

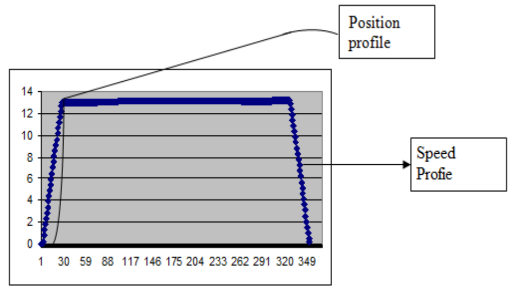

Fig 5: Simulated Speed profile and s-curve position curve.

When winding goes on the servomotor is rotated and wire is constantly supplied to the winder by speed control. The speed control of servomotor is decided by position of the dancer arm and a change in dancer arm is controlled by speed of servomotor. The controller card also gets the number pulses and direction feedback of servo so as to do winding and unwinding process for error control in servomotor. This is main tension control by maintaining constant mid position irrespective of tension variation and delivers proper tension by servomotor.

The stepper motor homing control is done by reading the proximity sensor for reference position of the spring and then the required back tension setting position is fixed by reading the memory location and then enabling stepper motor to move in direction specified for changing the spring position for tension control. Online change in tension can be enabled by using proper selection key provided and same changes are updated on memory and spring position is changed to new position for back tension control that is checked by calibarted tension meter manually.

To avoid errors of the stepper motor rotation for more than the spring length the maximum and minimum position is known and stored in memory and checked for each computation and stepper movement. The change in tension value occurs and final tension value used for winding is stored in non-volatile memory. The total length of spring would define the different tension values offered by the spring to the winding.

The tension calculations are done by below specified equation,

Tension required x Dancer arm length = the load applied(Y) x spring position

In the above equation the tension required(Eg : 80gms) is specified, the total dancer arm length(200mm) is know, the spring position(by stepper motor) is also know and so the load applied varies and that is controlled by the servomotor and stepper combination.

Different led's are provided to indicate the status of the device updating the spring position and error indication in case the stepper stalls or homing position not sensed etc.

As mentioned before a simple 7-segment displays are used for dispalying the tension value as it reduces the computation time and also complexity in programming for designer with other smart dispalys. And it not only displays the integer value but the floating point value can also be displayed and routines for proper conversions are taken care. As most functions are done using software, there is advantage of debugging errors easily and corrections could be updated in program without hardware changes.

IV. PID FIRMWARE IMPLEMENTATION

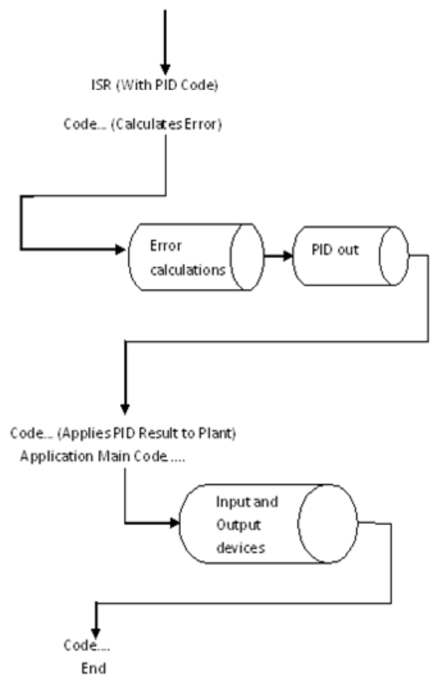

Fig 6: Flowchart PID firmware implementation

V. SIMULATION & RESULTS

An experiment was carried out at Synthesis Winding Technologies Pvt. Ltd. lab, and the results are presented as shown below. The testing of software on chip was done using Micro-C IDE tool which supports downloading and debugging online easier and compatible. As the code was written in C the working environment was Micro-C IDE that also has additional feature of generating assembly program also.

The PID routine was implemented on the PIC18F4431 Motor Control board. For the initial start of the motor, the PID gains were: $K_P = 0.1$, $K_i = 0.2$ and $K_d = 26$. These were scaled values. After starting the motor and running it close to its set speed, the integral gain was changed.

Table 1: Specifications of designed tensioner card

Wire Diameter	0.03 to 0.25mm
Tension range	10 to 150 gms
Resolution	±2%
Maximum line speed	20 m/s

The above table-1 gives the specification details designed for and tested for tensioner card that could be used.

Maximum line speed is the parameter that's specifies the capability of how fast the wire is delivered to tensioner through the wire router (servomotor) to the winding machine (Master control) that defines the through put of the controller card.

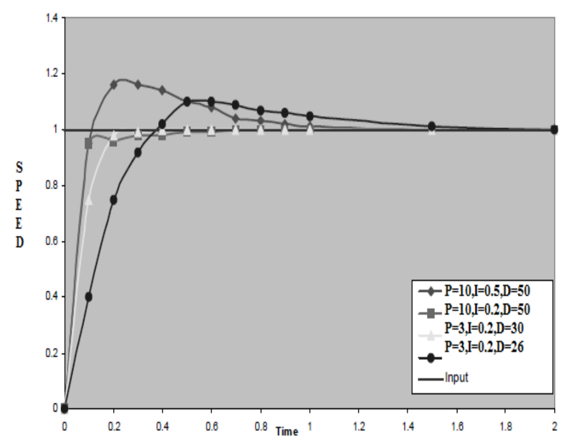

Fig 7: PID Controller graphic Response

Designing and testing of card delivers better performance and also low cost per device and so meets mid range analysis. The figure 7 shows the curve evaluated and tested for different values of gain factor and their response to gain factors like P, I, and D [2]. We can notice that time response curve with peak overshoot and under shoot can be used to find transient and steady state response. We find that after tuning for gain factors the steady state error was tuned to zero so as to get closed loop response with 2% resolution.

The figure 6 below shows the device for which the card was assembled with all peripherals and testing was done for mentioned specifications with main winding machine. This becomes one of a best device with least cost for winding application with auto control.

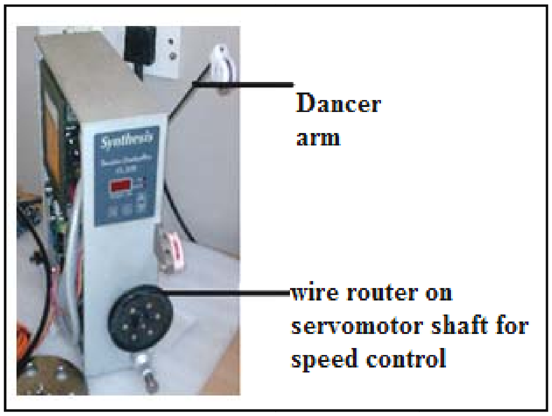

Fig 8: Final device with controller card and peripherals assembled

VI. DISCUSSION

Tensioner designed meets above specifications but has slight deviation in PID gain factors as the spring characteristics keep changing with aging. Because of this variation in gain factors there are some vibrations in dancer arm. This PID concept can be used for multiple applications and need not be only for tensioners. PID works better with servomotor than any other (DC or Induction etc).

Controller card designed for testing also has enhancing features of adding of many more peripherals for available card by using connecters.

The controlling mechanism and controller card can be used for any range of wires without modification but different spring for particular range of wires and aging of spring also cause problem in changing the tension value and so gain factors are to be updated frequently.

We can overcome the difficulty in usage of spring for tension control using magnetic tape, the technique from PC hard disk. The amount of current decides the position of the arm in hard-disk. And so same could be used for controlling dancer arm in tensioner. But this technique is yet to be implemented and used for further enhancement.

VI. APPLICATIONS

Coil winding application for making of transformers, capacitors, distribution transformers, with wire thickness and tension of wire specified.

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