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Proportional Integral Derivative controller Tuning application using Ziegler-Nichols method for Automated Plastic Packaging machine

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***Abstract*— As productivity is directly implied as profitability, for automation industries production lines have to be very efficient. So far, many techniques and a large variety of controllers are used to enhance and improve plant performance. In this paper, we have applied a tuning method of PID controller that is used for a heating element to reach a particular desired temperature at which plastic packaging will take place without any defect. To achieve an optimum temperature in less time, the PID controller which was initially self-tuned is modified by programming in STEP-7 and the tuning parameters were obtained by Ziegler-Nichols Method using MATLAB. Finally, the data result was implemented in an Industrial plastic packaging system study, and the procedure is explained.**

Keywords- heating element, PID controller, plastic packaging system, self-tuned.

I. INTRODUCTION

As accuracy plays a vital role in almost all the industrial processes, as the quality of product relies on it. One of the most popular methods, which is used in general purpose applications to achieve control over various system modules is to implement PID controllers. The popularity of PID controllers can be proved by the fact that in the mid-1990's they were used in more than 95% of control systems [1]. The process of tuning the controllers is time-consuming and tedious and also cannot assure the best performance every time whereas on the other hand implementing a tuning method while designing a controller will simplify work to a large extent giving results closer to the desired output.

In this paper, we are going to discuss Ziegler-Nichols Technique of tuning PID controller applied on plastic packing system to achieve control over the temperature of its heating element. The system forms pouches of plastic from a plain plastic sheet by melting both the edges of it and joining with each other with the help of a metallic jaw at a higher temperature that presses the plastic against a cylindrical support wall. Also, we will analyze the heating module, its thermodynamic behavior, and energy analysis. Heating elements are widely used in industries for boiling water or similar general purpose applications. These are generally supplied with electrical energy in controlled amount as per the application requirement. The design criterion of an element depend on various factors such as the material of heating element, shape, size and mechanical structure of element, the material to be heated, heating range of temperature for a particular application ,and various atmospheric factors such as surrounding temperature, humidity, time of the experiment, closed ambiance etc. The heating element, in this case, is a broad stripped type rectangular heating block element also referred to as a jaw, clamped or bolted on one side of the material to be heated making surface contact, generally solid to be heated. This category of heaters uses its surface area in contact to transfer thermal energy to the object to be heated.

The plastic sheet used with a material of polypropylene roller fed to vertically operated pouch forming system. A thin rectangular sheet is then folded and formed with the shape of the plastic pouch.

II. INTRODUCTION TO PROJECT

A. Production line

The project that is discussed, is based on an Automated Production line which classifies small shape objects according to their size , shape, and material by making use of different sensors such as Retro-Reflective sensor (SOEG-RSP-Q20-PS-S-2L) to detect presence of parts ,proximity sensor (SME-8-K-LED-24) to detect reference position, photoelectric sensor(Conch LS18D-40P) and inductive sensor (SIEN-M30NB-PS-K-L) to detect materialistic properties whether the object is made up of aluminum or steel. These sensors are mounted at different levels to detect the properties of objects and then the system performs packing of these pre-identified

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objects as per the customer demanded a set of characteristics into plastic pouches formed by the packaging system. The packing system has a roller of plastic sheet which is formed as a bag by bending and slightly melting two edges of it so that they can be attached to each other and a bag-like structure is formed. This job is done by a vertical heating element whose temperature is to be adjusted to a fixed value which should remain constant throughout. Hence we are making use of PID controller to achieve maximum control along with accuracy in operation.

B. Heating element

The heating element that we are using is this case is a specially manufactured jaw of bronze material. The design of the jaw is modified in order to ensure proper sealing and cutting of the packages which also includes a hollow slot inside the jaw for the installation of a temperature sensor i.e. PT100 so that the entire surface of PT 100 will be in contact with metal and reading so obtained will be more accurate.

Constants of heating element-
Total surface area=16965.95mm2
Contact area for sealing=3763mm2

One side of the rod is given curvature for proper contact with the cylinder of the equal radius that serves the purpose of support wall so that the plastic sheet material exactly under this area will get heated and hence merged into each other at edges. Also, six holes are drilled for installing this jaw on a metal arm which holds it at the perfect position.

III. ENERGY ANALYSIS

The vertical heating element is fed with the electric energy as an input through the PID controller so that only appropriate amount of electricity is given which will be converted into heat to rise the temperature of the bronze jaw.

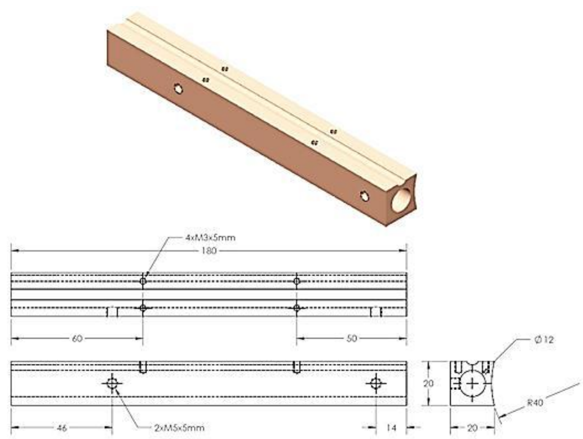

Fig.1.Mechanical design of heating element

The electrical input that is given as the energy from the system will be

E(el)= Vs * Is Watt (1)

Where: Vs - rated supply voltage
Is - rated supply current

Initially, the jaw is in thermal equilibrium with ambient air in its surrounding. This condition of equilibrium is disturbed when an electric current 'I' is passed through it. First law of thermodynamics is often used to detect an unknown temperature of the system. Here heat transfer takes place through convection and radiation from the surface. Energy generation takes place due to Ohmic heating of jaw.
By applying first law of thermodynamics we can say,

E(g) - E(out) = E(st) (2)

Where E(g) is energy generated, E(out) is energy outflow and E(st) is the stored energy in it.

The energy is generated due to the process of electrical heating to increase the temperature of the jaw to the desired level.
Hence,

E(g)=I2*R*L (3)

Where 'I' is the electric current passed through the rod by the system whose amount is controlled by software and 'R' is electrical heating resistance per unit length of the heating element.

The heating process takes place within the control volume can also be expressed by volumetric heat generation rate let it be 'q'.

The rate of generation of heat in the jaw is then

E(g)=q * volume of the jaw.

Where q=I2*R*L*A

Here 'A' is cross-sectional area of the jaw and 'L' is the length of the element. During the heating process, the outflow of energy takes place due to both convection and radiation from the surface of the jaw. Equations for it will be,

E(out)=h(Surface Area of the rod)(T-T∞) +
εσ(Surface Area of the rod)(T4-T4sur) (4)

Where - h is the convective heat transfer coefficient

ε is the emissive coefficient of the object,

σ is Stefan-Boltzmann constant.

The change in energy storage is due to change in temperature. Hence,

$$E(st)=\frac{dU_t}{dt}=\frac{d}{dt}(\rho VCT) \quad (5)$$

Where ρ is the mass density of the material of rod, 'V' is the volume of the jaw and c is the specific heat.

Here E(st) is associated with the rate of change in internal energy of the heating element. Substituting the rate equation into equation (1)

$$I^2RL - h(S.Area)(T - T\infty) - \varepsilon\sigma(S.Area)(T^4 - Tsur^4) = \frac{\rho CALdT}{dt}$$

Hence

$$\frac{dT}{dt}=\frac{I^2RL-h(S.Area)(T-T\infty)-\varepsilon\sigma(S.Area)(T^4-T^4sur)}{\rho CAl} \quad (6)$$

The heating process continues till element reach its desired temperature. At this time since there is no further change in internal energy E(st) will tend to be constant, in this situation the system provides electric input that is only necessary to compensate losses and current is supplied continuously by a controller that varies with fluctuations in heating losses in order to maintain a constant temperature.

Putting the values in above energy equation (2) at steady state,

h(Surface Area of the rod)(T-T∞) +
εσ(Surface Area of the rod)(T4-T4 sur)= I2*R*L (7)

IV. CONTROL SYSTEM ANALYSIS

A. Problem statement

In the previously designed control system where the controller was designed using auto-tuned technique temperature of the jaw was not maintained constantly hence it was either burning the plastic due to over melting of it or along the line few voids were there where the sheets are not continuously attached to each other. Tuning techniques are nothing but methodologies which give us set of parameters needed to feed to the controller for its operation. The time taken for the system to reach desirable temperature was approximately 20 minutes and also with oscillations which indicate the system was having large settling time.

The temperature that we want to obtain is the desirable range of system output, slightly varying as per the atmospheric conditions. The controlling of the system is further done using SIMATIC manager STEP-7 software where the program is written for PID controller. The system is initially an open loop system where feedback and controller are added to make it closed loop system to achieve desired control of temperature.

B. Open loop system

By writing a small program in STEP-7 software we can energize the heating coil by setting particular signal high. Hence the unit step signal is given to the system to have an observation of the characteristic behavior of the system under open loop control.

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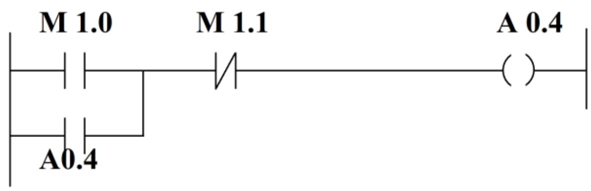

Fig.2. STEP-7 Program for open loop system.

The above program needs to have one more amendment in the reading obtained at pin no PIW296 which is the machine level, scaled big digit value of reading of RTD PT. 100. Following procedure is followed to obtain the actual user readable value.

C. Procedure for conversion

Obtained input value of PT100 signal from particular contact pin number that is assigned through software is originally a huge value, that needs to be converted into human understandable form and hence this procedure needs to be followed. It is first converted from an integer to double integer then saved in memory location MD 324. Again this value stored in MD324 is converted from double integer to real and stored in a memory location MD320. Now, this value is divided by 10 to obtain actual temperature that is set in degree Celsius reading value.

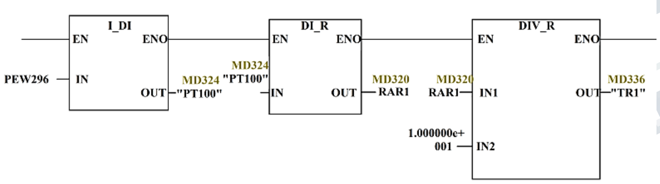

Fig.3. Step 7 program line for data conversion

The signaling is done by interfacing SIMATIC manager software with WIN-CC flexible software. This WIN-CC flexible creates graphical instruction and information display on the control panel. On running the program in STEP 7, Win-CC will create a file in its data log saving all the temperature readings per interval time generally 1 second in Microsoft Excel format.

The response so obtained in the figure (4) is by applying unit step signal to the system. Starting from room temperature of 23degree centigrade the curve will slowly increase its slope. After a certain time, the electric energy supplied will be equal to losses and temperature will not rise further. This is the point in the characteristic where we get saturation line and a further increase in heating time will not increase the temperature of the jaw.

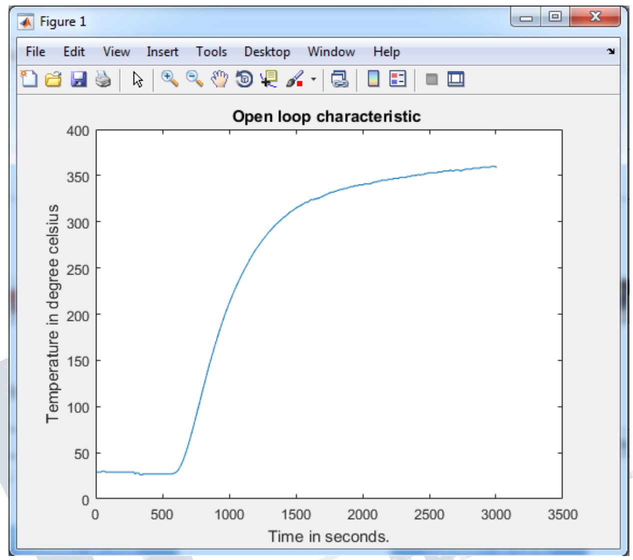

Fig.4. open loop characteristic

D. Control system implementation

Let us consider the process feedback system shown in the figure (5). The transfer function of the plant can be written. [2]

$$G(s) = \frac{k}{1+ts} e^{-\tau s} \quad (8)$$

Where- ‘G(s)’ is an overall gain of the system, ‘K’ is the steady state gain constant, ‘τ’ is the time delay and ‘t’ is the time constant of the system.

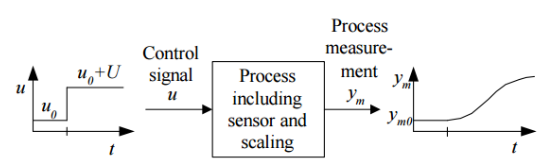

Fig.5.process control system

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The system when applied to proportional integral and derivative controller its transfer function is given by [3]

$$G_c(s) = K_c(1 + \frac{1}{T_i s} + T_d s) \quad (9)$$

V. ZIEGLER-NICHOLS METHOD

One of the popularly used principal methods of tuning the PID controller is Ziegler-Nichols that gives us set of parameters for PID controller designing. The two of its type which popularly used are, one is unit step response method and another is ultimate frequency method. In the first method of unit step response, the system is given the step signal of magnitude one as input and output of the system is observed in absence of feedback as open loop system and its characteristic graph is plotted. Then the tangent line is drawn at the point of inflection of the curve where the slope is maximum.

The method can be applied in this particular example as Zn method is applicable in the cases where the response is monotonic that is s-shaped output characteristic. [3]

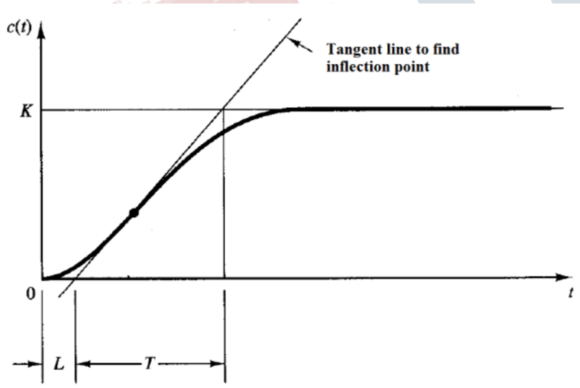

Fig.6.Ziegler Nichols Method

From the graph values of L, T and K are found out. Then using the following table the PID controller parameters that are Proportional gain constant (Kp), Integral time (Ti) and derivative time (Td) are calculated.[2]

TABLE I: Ziegler Nichols parameters

Type of controller	K_p	T_i	T_d
PID	1.2/a	$2 \cdot L$	$0.5 \cdot L$

Where

$$a = \frac{L}{T} * K \quad (10)$$

- ***Detailed Procedure to find inflection point***
  The inflection point is also called as a point of inflection, flex, the inflection of a curve, which is nothing but the point at which the curve changes its direction i.e. from convex to concave or vice-a-versa. This point can be calculated by taking the double derivative of the equation and equating it to zero. The roots so obtained are then validated and suitable point is selected as inflection point of curve

- ***MATLAB code to find inflection point of curve***
  The characteristic equation of open loop plot of the system obtained in MATLAB curve fitting and a suitable degree of the equation is chosen here taken as 4.Higher order equation will be closer to the actual graph of the system but it will give difficulty in calculating roots of the equation by equating double derivative. Also, the higher order terms do not play a major role in designing the controller.

MATLAB CODE-

```
syms x

lore=9.9e-11*x^4 - 3.7e-07*x^3 + 0.00028*x^2 + 0.3*x -
3.6 ;

sd=diff(diff(lore,x),x);

pretty(sd)

v=solve(sd,x);

pretty(v)

hold on
```

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plot(v,subs(lore,v),'*')

msgbox(‘click the point marked as ‘*’on the graph ’);

[x,y] = ginput(1);

By plotting characteristic equation curve and finding inflection point following graph is obtained.

MATLAB output screen-

```
                           4                            3         2
   3829876996539145 x        6989102394647075 x       7 x     3 x    18
-------------------------- - ----------------------- + ----- + --- - --
38685626227668133590597632   1888946593147858085 4784   25000    10     5

                           2
  1148963098961 7435 x       2096730718394 1225 x      7
------------------------- - ---------------------- + -----
9671406556917033397649408   944473296573929042 7392   12500

/ 715684085211860480   512 sqrt(1264050839343112934085800194046 73153) \
| ------------------ - --------------------------------------------- |
|   765975399307829                   287240774740435875             |
|                                                                     |
| 512 sqrt(12640508393431129340858001940467 3153)   715684085211860480 |
| --------------------------------------------- + ------------------ |
\                287240774740435875                  765975399307829  /
```

Fig.8.MATLAB Output Screen.

The graph that is plotted indicates two points of inflection the one which we are selecting is based on the range of desired output. As the tangent to be drawn is at a point that arrives before saturation of curve.

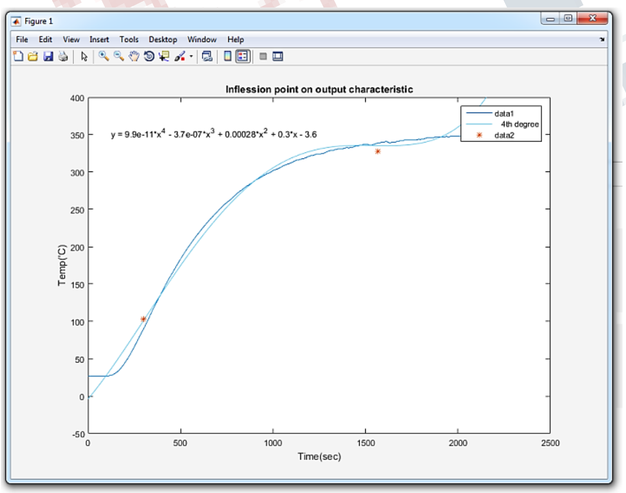

Fig.9.Matlab graph for Inflection point

- ***Calculations-***

Values obtained from the graph are,

L=125.1680 seconds

T=646.8414seconds

K=334.6386

Substituting above values in equation (10), value of a = 64.7547

Here the values have arrived that are parameters using table (1) for tuning the controller are-

- Kp = 0.01853
- Ti =250.336 seconds
- Td =62.584 seconds

Thus we get all the parameters of PID controller and apply them to the system by setting these values in the controller.

CONCLUSION

This paper demonstrated the application of Ziegler Nichols tuning method along with the process of calculations of tuning parameters using MATLAB and the implementation of this control system on plastic packaging line that is made to run using SIMATIC Manager STEP-7.

Applying thermodynamic analysis and energy equilibrium principle, the exact temperature range needed to heat the plastic is calculated and the element is brought at that temperature in shorter duration and PID controller controlled the current to keep the temperature constant. Hence by the implementation of prescribed method, better accuracy is achieved in shorter settling time for the system improving its performance and productivity.

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