A STUDY ON THE CONVENTIONAL AND FUZZY CONTROL STEEL-CUTTING PROCESS

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ABSTRACT

This work begins with the presentation of a conventional steel-cutting process, in which programmable logic controllers (PLC) and optical sensors are used. Later, a new fuzzy control method is proposed for the same application. The proposed system is simulated in MatLab/SIMULINK environment and the dynamic performance characteristics are computed and compared with those of experiments of the conventional system. Encouraging results for fuzzy control application are obtained.

I. INTRODUCTION

There have been many cutting applications in industry for tension controlled rolling mill systems. Steel-strip cutting is one of them. In these systems, there is a loose part to provide buffer between two rolling mills. In Figure 1, a schematic diagram of the system is shown. As it is seen, there is a loose part between two drums. The purpose is to avoid the additional tension occurring between two drums, during cutting. Generally a dc electric motor rotates the mill and drags the strip [1]. Another servomotor executes the cutting process. During the cutting process, rolling of the drag motor is interrupted momentarily, in the mean time right hand side of the system continues to rotate, therefore the depth of the loose part between two drums gets higher. In opposite, when dragging motor speed becomes high, loose part diminishes and additional tension builds up, which may yield damage on the strip. In order to prevent these actions, depth of the loose part of the strip should be detected. When the loose part of the strip's depth becomes low, motor speed goes down and loose parts bottom moves downwards. In opposite, when the depth becomes low, then the speed of the motor is increased to avoid excessive loose. Without this action, loose part of the strip may even touch the ground. Thus, dragging motor's speed should be controlled continuously.

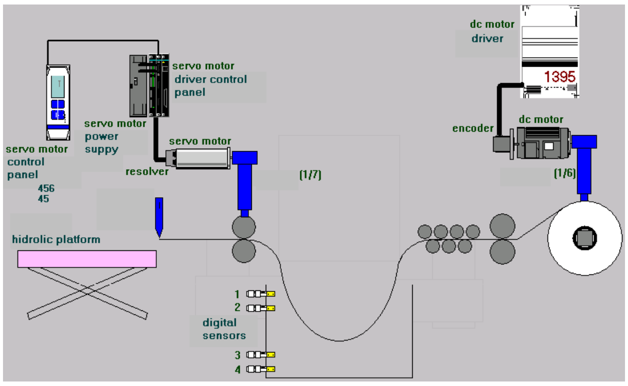

Figure1. A PLC controlled steel cutting process.

Five optical sensors provide information about the depth of the loose part, which is in a pit of approximately 2 m. depth. Position information collected from the optical sensors is transferred to a programmable logic controller (PLC) [2]. Also motor current, voltage, power and speed information are collected by a SCADA system. The PLC evaluates this information and also the required position information and then, decides on the speed of the motor [3]. Finally, updated speed signals are produced and send to the power-electronic circuit, which supplies the motor. In this application Allen Bradley PLC5 programmable logic controller has been used.

This system has some disadvantages. Firstly, optical sensors are expensive. Secondly, since position information is collected in five steps, position observation is not very accurate. It has been widely accepted that, there is a need to provide a better control with lower cost.

This paper proposes a new cutting process using fuzzy control [4,5]. As it is known that, fuzzy control is based upon fuzzy sets in which, sets are not defined as zero or one. Instead, affiliation may take any value between one and zero, which is called membership value. Control decision is taken by fuzzy the fuzzy system, which uses fuzzy membership functions and fuzzy rules. Finally, whole system is defuzzyfied and required value is obtained. There have been many successful fuzzy applications in various process control systems. Fuzzy control is particularly useful where human experience or human evaluation is replaced.

In this process, whole systems are simulated in a personal computer and fuzzy model is inserted in the simulation model. Five optical sensors are replaced by one low cost ultrasonic sensor. Position information of the loose part of the strip is collected continuously and sent to the personal computer in which fuzzy algorithm is located. Fuzzy decision-making process is executed and required voltage information, which is directly related with the speed of dc motor, is produced. The detailed information of the study is presented in the following sections.

II. DEVELOPMENT OF FUZZY CONTROL SYSTEM

Servomotor operates in steel cutting process in start-stop modes [6,7,8]. In other words it rotates and becomes standstill in short intervals. Obviously, this mode of operation adversely affects the system. Provision of a loose part for a continuously moving strip, compensates the effect of starts and stops. As it was explained above, four digital sensors produce position information of the loose part of the strip., which is a stepwise sensing. In the proposed method, an ultrasonic sensor will be used to monitor the position continuously, as shown in Figure 2 in which the distance between point a and b is accurately measured. In order to define the position error, point f is selected as reference. Thus, error is calculated as,

$$e = | ag | - | af | \qquad (1)$$

In order to avoid the bottom and top limits, which reflect touching ground and complete horizontal conditions respectively, it is assumed that error will vary between +0.9 and – 0.9 limits. Calculated (e) value will be first input variable of the fuzzy logic controller.

It is known that, error (e) alone is not adequate; variation speed of the error (Δe) should be taken into consideration. For example, even though error is approaching zero, if speed of it is high, then error is not going to stop at zero error position and it is going to exceed equilibrium point immediately. (Δe) is defined as the difference between two successive error values.

$$\Delta e = e(t_2) - e(t_1) \qquad (2)$$

Δe is the second input variable of the fuzzy controller.

It is known that, membership functions are important part of fuzzy logic controller development. Particularly, rule base system with if then rules must provide correct information. For steel cutting process, distance and speed of the loose part of the strip steel in the pit is chosen as independent input variables and the following membership functions are developed.

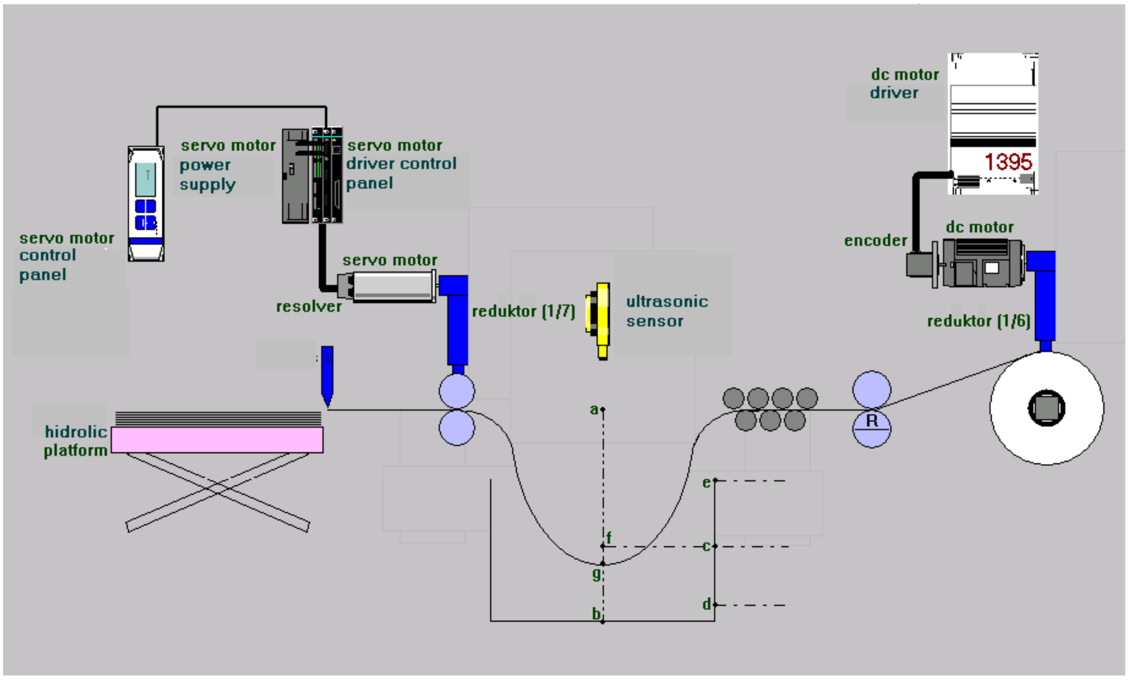

Figure 2. Fuzzy logic steel cutting process.

Five membership functions are defined for input and output variables. Following definitions are necessary for membership functions.

PB : variable is positive and big

PO : variable is positive and medium
S : variable is zero
NO : variable is negative and medium
NB : variable is negative and big

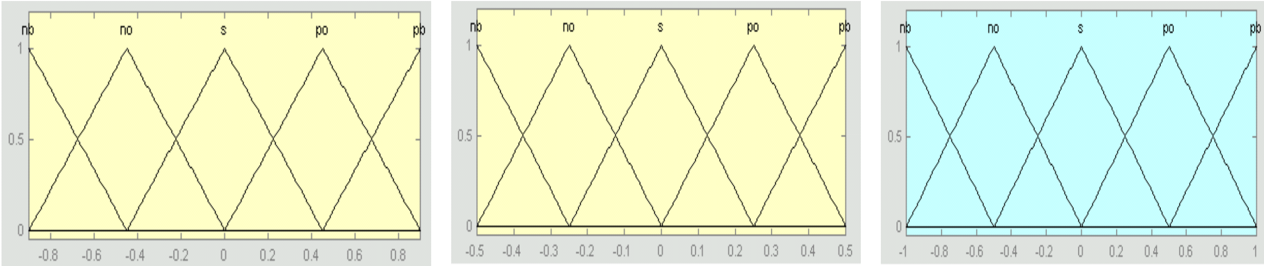

Figure 3, 4, 5. Membership functions for distance (e), Membership functions for speed (Δe), Fuzzy rule base output membership functions.

According to the operational condition at that particular moment, fuzzy controller evaluates the situation and produces a single output. The relationship between inputs and a single output is established by fuzzy rules. Fuzzy rules of a dc motor control system for steel cutting process are given in Table 1 [9,10,11].

Table1. Fuzzy logic rules of the system.

Δe .˙ e	nb	no	s	po	pb
nb	nb	no	no	-	-
no	no	no	no	-	-
s	no	no	s	po	po
po	-	-	po	po	pb
pb	-	-	po	pb	pb

The output of the fuzzy block produces information to reduce the error, then control system acts accordingly, either accelerates or decelerates the DC motor. Output membership function takes values between (+1) and (-1). When output membership function takes (+1) value, this means motor should accelerate immediately with a full power. In opposite end, if output membership function is (-1), then motor should decelerate immediately with a full power. Any value between these limits reflects accelerations or decelerations with a suitable power, which is proportionally lower than maximum power values. In order to achieve the required speed, fuzzy output signal of which value is between (+1) and (-1) limits, is multiplied with speed and supplied to the control board of the servo system. Servo controller converts this information to the voltage supply information of dc motor. Finally, required armature voltage is produced by power electronic supply. In Figure 6., schematic diagram of the fuzzy controlled system is presented.

III. SIMULATION OF FUZZY STEEL CUTTING PROCESS

An existing steel cutting process in industry, which uses a PLC and four digital position sensors, is handled first and fuzzy control scheme described above is replaced. The proposed system above is modelled by using Matlab/SIMULINK programme [12]. This model takes all electrical and mechanical quantities into account. DC motors armature-winding parameters, inertia and friction coefficient are all represented in the model. The model of ultrasonic sensor is also developed and inserted in the system. The fuzzyfication and defuzzyfication process and compatibility with the simulated model is inherently achieved by using Matlab Fuzzy Logic Toolbox.

In fuzzy strip-steel cutting process, distance information (h) showing the level of depth of the loose strip is very important. This information is produced by an ultrasonic sensor, which is calculated by the method described in Figure 7.

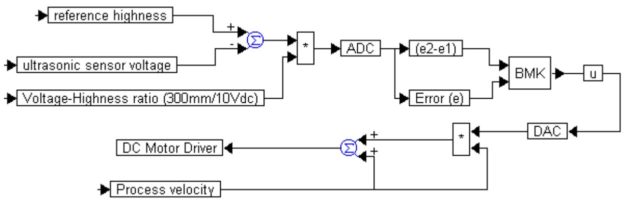

Figure 6. Schematic representation of fuzzy controlled system.

$$h = \sqrt{[(k^2/4) - m^2]} \quad (3)$$

By considering the speed difference between DC motor and servomotor, the variation of the depth of the loose-strip in the pit can be calculated as,

$$k(t_n) = k(t_n\text{-}1) + [V_{dc}(t_n) – V_{sm}(t_n)](t_n – t_n\text{-}1) \quad (4)$$

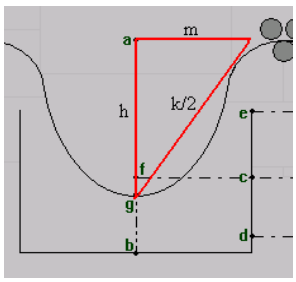

Figure 7. Calculation of h value of the loose strip.

In order to produce real data to the simulation system, servomotor cutting-speed values are collected by a SCADA system and a look up table is prepared [13]. This table is inserted in the simulation system. For dc motor speed, initially bant speed is used as reference, later speeds produced by fuzzy system are used and motor speed is varied accordingly. The SIMULINK model of fuzzy steel-cutting process is depicted in Figure 8. Three-dimensional representation of the relationship between input and output parameters are shown in Figure 9.

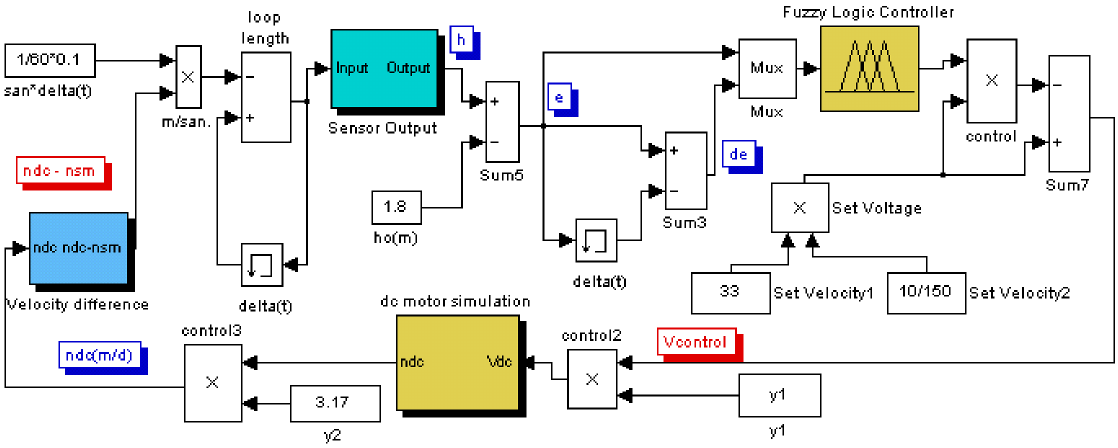

Figure 8. SIMULINK Model of the system.

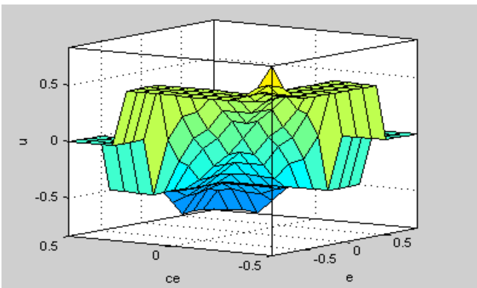

Figure 9. Relationship between input and output parameters.

IV. COMPARISON BETWEEN CONVENTIONAL AND FUZZY CONTROL

The actual industry application of a strip steel cutting process, which uses PLC and digital position sensors, is handled for comparison. Initially, online operational values of the existing system have been recorded. Later, performance characteristics of the fuzzy controlled system have been computed and compared with those of experiments. Actual recorded and fuzzy computed rotational speed curves of dc motor for 33 m/s linear strip speed are shown in Figure 10 and 11 respectively. It is seen that, fuzzy system can respond faster to the excessive oscillations than existing system. Same process has been done for 61 m/s strip speed and similar results have been obtained, which are depicted in Figure12. and 13.

The speed of strip steel versus time curves for fuzzy system shows that, there will be less speed disturbances during cutting.

Since fuzzy system provides continuous position control and adjusts the speed accordingly it provides smooth operation property. This would yield more reliable operation with less waste material. Interruptions would be less than conventional one. In addition to having better performance characteristics, since it uses only one low cost sensor, fuzzy controlled system will also be cost effective.

It must be expressed that, fuzzy calculations is based upon the simulation model. There is a possibility to get inferior results when build and test such a system.

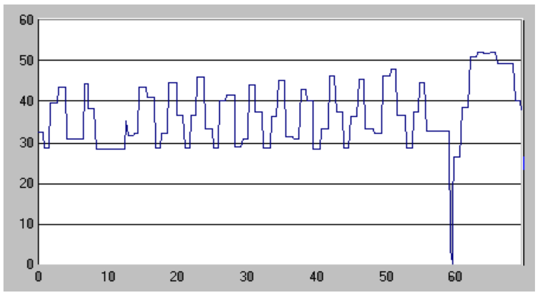

Figure 10. DC motor speed variation for conventional control system, v = 33 m/s.

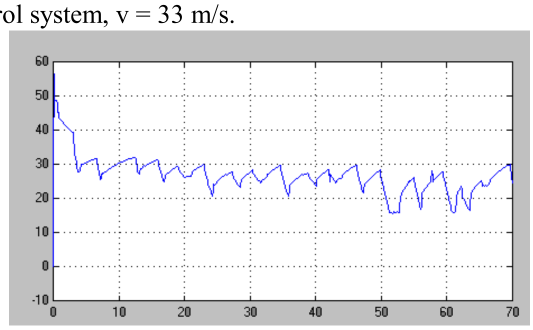

Figure 11. DC motor speed variation for fuzzy control system, v= 33 m/s.

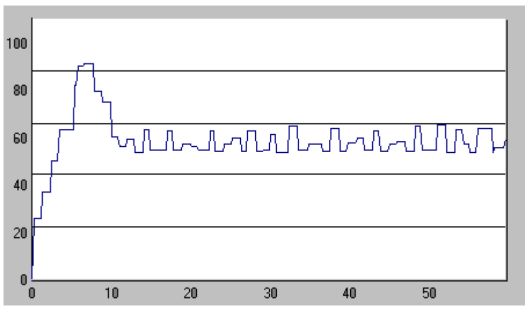

Figure 12. DC motor speed variation for conventional control system, v = 61 m/s.

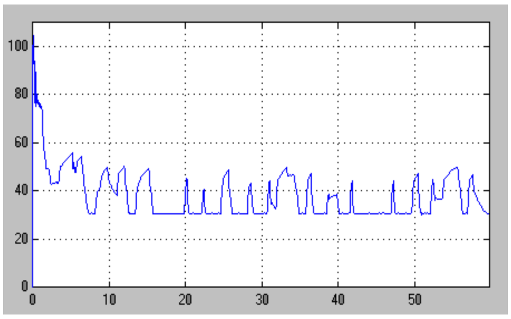

Figure 13. DC motor speed variation for fuzzy control system, v= 61 m/s

V. CONCLUSION

A new fuzzy control method is proposed for industrial steel-cutting process.

- The simulation of this system has been achieved in SIMULINK environment.
- Performance characteristics have been computed.
- Experimental performance values of existing system have been recorded. This system uses four sensors and a PLC to control the position of the strip-steel.
- Comparison between computational and experimental results have yielded that, proposed fuzzy system might be superior to the existing system if it would have been replaced. Time response is shorter, speed control is better, possibly reliability is higher and the cost is lower.

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