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Implementation and Performance Analysis of a Three Inputs Conventional Controller to Maintain the Cane Level During Cane Crushing in FPGA using VHDL

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***Abstract*- Raw sugar is produced from the cane juice which is extracted from the series of five to six cane crushing mills. The uneven supply of cane during cane crushing affects juice extraction efficiency of the mill. Seventy to seventy five percent of the cane juice is extracted from the first mill and thus this mill plays an important role in overall efficiency of sugar production in a sugar mill.**

This research paper deals on the design methodology, implementation and functional verification of a conventional controller to maintain the cane level during cane crushing in Field Programmable Gate Array (FPGA). The VHDL model of proposed controller is developed using Xilinx ISE Design Suite 14.5.

Key words: sugar mill, conventional controller, cane level, FPGA, VHDL

I. INTRODUCTION

The function of the sugar factory is to produce crystal sugar from the juice in cane delivered to the factory. The juice extraction from the cane takes place by passing it through a series of five to six mills called the milling train. From the series of mills 70-75% of the total juice is extracted from the first mill [1].

The cane is first passed through two sets of rotating knives which converts the cane billets into cane fibre by hammering it by shredder knives. This cane fiber is called prepared cane. The cane fibers are feed to Donnelly chute and cane juice is extracted by crushing fiber in two, three or four rolls of the mill. This process is repeated through sets of five/six mills until last mill is reached [2] [3].

If the level of prepared cane is very low then there may be chances of passing of cane uncrushed from the mill and if the level of prepared cane is very high then there is a chance of mill breakdown due to heavy load on mill so the level of cane fiber in Donnelly chute is very crucial. The amount of cane fiber varies due to non-uniformity of cane supply. If the level of cane fiber falls below the desired level then more cane fibre is to be dumped in chute and if the level of cane fiber rises above the desired level the raised level is to be brought back to desired cane level [4].

In this paper we developed a controller with an aim of maintaining the cane level at constant height in Donnelly chute. The conventional controller is developed with the help of VHDL [5] and implemented in FPGA [6]. VHDL is one of the most accepted and widely used languages for describing a digital system. VHDL has been approved by IEEE as a standard language for designing hardware. VHDL stands for Very High Speed Integrated Circuits Hardware Description Language.

In 1987 standard version of VHDL “IEEE Std 1076-1987” was launched for industrial use. In 1993 language was upgraded with new features and upgraded version “IEEE Std 1076-1993” was launched [7]. Subsequently, many computers – aided engineering companies put lot of efforts into developing tools based on VHDL. At this point of time VHDL is supported by nearly all design automation tools and is widely used in the design cycle for Simulation, Synthesis and Testing [8]. The most important part of VHDL is its technology independency [9].

The Xilinx ISE 14.5 is used for creating VHDL model, ISim simulator is used for functionality verification and Xilinx XST tool is used for the synthesis of VHDL model. Performance of conventional controller is analyzed for six different cases.

II. PARAMETERS OF A 2-ROLL MILL

Two rolls and the chute arrangement used for cane crushing are shown in Fig.1. It has been investigated that the physical structure of mill effect the feed depth at which maximum crushing rate can be achieved [10]. The diameter of roll when measured from the tip of groves is Do and Dg is the length of groves and D is the average diameter of roll. The mean diameter of roll is given as:

$$D = D_o - D_g \qquad (1)$$

Where D_o is the outside diameter of roll and D_g is Groove Depth. The opening measured between the two rolls outside diameter is called as nib opening or set opening. The opening measured between the mean diameters of two rolls is called work opening [11] and is given as:

$$W = W_s + D_g \qquad (2)$$

Where W_s is nib opening. The surface speed of roll is given as:

$$S = (\pi \times D \times N)/60 \qquad (3)$$

Where S is surface speed of roll in cm/s and N is roll shaft speed in rpm. The thickness of cane blanket at the feed opening of the mill effects the juice extraction from the mill. The optimum feed depth is investigated and found as follows:

$$B_c = (W+D)/2 \qquad (5)$$

Where B_c is the optimum feed depth in cm [11]. The contact angle is the angle between the line joining the center of the two rolls and the line joining the center of roll to the point where chute touches the roll [12]. The contact angle is given as:

$$\text{Cos}\ \alpha = (D + W - B_c) / D \qquad (6)$$

The escribed volume is the volume of prepared cane passing through the work opening of the mill [12] and is given as:

$$Ve = L_r \times D \times S[1 + (W/D) - \text{Cos}\ \alpha)\ \text{Cos}\ \alpha \qquad (7)$$

Where Ve is escribed volume in (m^3/s) and L_r is roll length in cm. The average speed of cane blanket at the point where chute touches the rolls is given as:

$$S_f = S\ \text{Cos}\ \alpha \qquad (8)$$

Where S_f is the average speed of cane blanket in cm/s. At the entry of chute the volume of cane passing the entry plane is given as [13]:

$$V_e = L_r \times B_c \times S\ \text{Cos}\ \alpha \qquad (9)$$

The fibre rate is the amount of fibre crushed by mill in one second and it is given as:

$$Q_f = (Q_c \times f)/ 100 \qquad (10)$$

Where Q_f is the fibre rate in Kg/s, Q_c is cane crushing rate in Kg/s and f is the percentage of fibre present in cane.

The prepared cane is carried by cane carrier and dumped in chute. The chute is inclined to horizontal and the angle of inclination and the dimension of chute vary from one mill to other. The length of chute (L_c) is 180cm, width (W_c) is 43.5cm and depth (D_c) is 183cm. The Roll length (Lr) is 183cm, roll diameter (D) is 75.5cm and work opening (W) is 11.45cm. The optimum angle (α) calculated from (6) is 61°. The optimum feed depth (B_c) calculated from (5) is 43.5cm.

It is required to select parameters for a mill which can crush 2000 tons cane per day (tcd). Allowing about 10% excess crushing, the maximum mill capacity should be 2200 tcd. For achieving 2200 tcd crushing of cane the mill must be able to crush 26.6Kg/s cane [14]. The amount of cane crushed by mill in one second is termed as flow rate and denoted as Q_c in this paper. We can relate flow rate with cane density and escribed volume as follows:

$$Q_c = \rho_c V_e \qquad (11)$$

Where V_e is escribed volume and ρ_c is density of cane (350Kg/m^3). The escribed volume calculated from (10) is 0.076m^3 /s. The surface speed of roll is calculated from (10) is 16.6cm/s. The average speed of cane blanket when it touches the roll surface is calculated from (8) is 9.5cm/s. If the cane crushing rate is 26Kg/s and the fibre percentage in cane is 15% then the fibre rate calculated from (10) is 4Kg/s. The Pressure required to feed mill is given as follows [10]:

$$p_2=[\int_{\beta}^{\alpha} pv\cos\theta\tan(\theta-\beta)\,d\theta]/(Bc/D) \qquad (12)$$

Where p_2 is the pressure required at chute exit, p_v is the pressure applied to the cane, θ is the angle with which chute is inclined to horizontal, β is the angle with which mill will be feed without the application of external force. β is given as:

Where $\beta = \tan^{-1}\mu \qquad (13)$

Where μ is the coefficient of friction and its value selected in this application is 0.3. Solving (12) after putting α = 61°, θ=61° and β = 20° gives as:

$$p_2 = p_v(2.042) \qquad (14)$$

The p_v is given as:

$$p_v = 36.9\ (100\ C_f - 3.3)^2\ [15] \qquad (15)$$

Where C_f is filling ratio and is given as:

$$C_f = \gamma\ /1260Kg/m^3 \qquad (16)$$

Where γ is called compaction and its value in this application is 52Kg/m^3. The value of C_f calculated from (16) is 0.041. The value of the pressure applied to the cane (p_v) is calculated as 23.6lb/ft^2 (0.01152Kg-force/cm^2) and the pressure required at chute exit (p_2) is calculated as 0.02352Kg-force/cm^2(2.3KPa). In an open chute, the pressure due to fiber is given as:

$$p_2 = \rho c\ (\text{Sin}\ \theta - \mu\text{Cos}\ \theta)L\ [15] \qquad (17)$$

Where L is the height of cane in chute and the value of θ in this application is 61°. The height of cane in open chute is calculated from (17) as 92cm. In order to minimize the failure rate of fiber the cane must be maintained at 90cm in chute. The cane fiber is assumed to fail in a similar was to soils. The 'failure ratio in fiber is the ratio of maximum shear stress to shear strength of fiber. A volume of prepared cane contains fiber, air and juice. When fiber is compressed in a pair of roll then air is expressed until fiber contains only fiber and juice. Any further compression of fiber expresses juice. It has been investigated that failure rate of fiber decreases with the increment of pressure applied on fiber at mill opening but beyond certain value the failure rate starts increasing with the increment of pressure. The failure rate is minimum (0.04) when the feed pressure is 2kPa [16] [17].

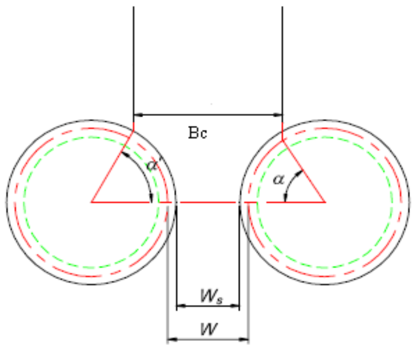

Fig.1. Two Rolls and Chute Arrangement of a Mill

III. CONVENTIONAL CONTROLLER AND INTERFACING CIRCUITS

The proposed conventional controller based system used to control the cane level is depicted in Fig.2. The prepared cane is dumped in Donnelly chute of height 180cm. The Rake Carrier which carries the prepared cane up to Donnelly chute is of length 800cm, width 150cm and its weight is 500Kg. The rake carrier is run by a motor whose speed can be varied from 19rpm to 101rpm. The amount of prepared cane on rake carrier varies from 500Kg to 1000Kg. This variation of prepared cane can be measured with a load cell. Due to uneven supply of cane billets the level of prepared cane varies in Donnelly chute. This variation of cane level is measured with the help of a light sensor. The two rolls TRF 1 and TRF 2 rotates in anti-clockwise direction with the surface speed in the range from 12cm/s to 16.6cm/s. The steam turbines are used to rotate the rolls in sugar mill. The final product left out after the extraction of juice from the milling train is called baggasse. This baggase is used as fuel to produce steam and this steam is used to run turbines. In a sugar mill the supply of stem to run turbine is not uniform therefore the rotational speed of rolls vary. A tachometer can be used to calculate the speed of rolls.

The three variables are weight of prepared cane on rake carrier, level of cane in Donnelly chute and the rotational speed of rolls. A control algorithm is developed in this paper with an aim of changing the speed of rake carrier depending upon the values of the three variables so that the cane level in Donnelly chute will remain constant.

Various hardware components required for a cane level control mechanism are as follows:

A. *Load Cell* – It is used to measure the amount of cane available on rake carrier. Its full capacity is 1500Kg with 2mV/V, 10V excitation. The load cell generates 13.3µV/Kg, 13.3mV for 1000Kg and 20mV for 1500Kg. The weight of carrier is 500Kg and the weight of cane will vary from 500Kg to 1000Kg. Therefore load cell will generates a voltage in the range of 13.3mV to 20mV in present application. A load cell signal conditioning system is designed by using OrCAD pSpice software as shown in Fig.3. The purpose of signal conditioning system is to change the voltage range 10mV-20mV to 0-2.5V. The output of load cell signal conditioning system is connected to an eight bit analog to digital converter (part number 804). The ADC is calibrated to have a step size of 9.77mV. The digital output corresponding to different load condition on carrier is given by Table 1.

Example I – The signal conditioning system generates 1.25V when carrier has 750Kg cane. The simulated output of signal conditioning system is shown in Fig.4.

The ADC output is given as follows:

$D_{out} = V_{in} / SS$ (18)

Where V_{in} = Applied input to ADC = 1.25V

SS = Step size

When V_{in} is 1.25V and SS is 9.77mV then from (18) the output of ADC comes to be 128 in decimal or 80H in hexadecimal.

B. *Height Sensor* – It is used to measure the cane level in chute. A schematic for sensing the height of cane level in chute is shown in Fig.5. A light sensor is placed at height of 300cm from the base of chute. When the cane is at the base of chute then sensor will generate 20mA and when the cane is at 180cm height then the sensor will generate 8mA. A height sensing signal conditioning system is designed by using OrCAD pSpice software as shown in Fig.6. The purpose of height sensing signal conditioning system is the conversion of the current output of height sensor into voltage. The output of height sensor to measure cane level from 0 to 180cm is 20mA to 8mA respectively. The output of conditioning system is from 0.8V to 2V. The output of load cell signal conditioning system is connected to an eight bit analog to digital converter (part number 804). The ADC is calibrated to have a step size of 9.77mV. The digital output corresponding to different level of cane in chute is given by Table. 2.

Example II – The height sensor generates 16mA when the cane at 60cm above mill. The signal conditioning system generates 1.6V and the simulated output of signal conditioning system is shown in Fig.7. The output of ADC is given by (18) and it comes to be 164 in decimal or A4H in hexadecimal. The output of the ADC is again complemented and it comes to be 5B in hexadecimal.

C. *Tacho generator Sensor* – It is used to measure the rotational speed of roll. The roll rotates from 12.0cm/s to 16.6cm/s. The relation between the surface speed of roll and it's rotational speed is given as:

$R_s = (R_{rpm}/60) \times C_r$ (19)

Where R_s = Surface speed of roll (cm/s)

R_{rpm} = Rotational speed of roll (rpm)

C_r = Circumference of roll (cm)

The Circumference of roll is given as:

$C_r = \pi \times D_{roll}$ (20)

Where D_{roll} = Diameter of roller (cm)

The roll diameter in this application is 75.5cm therefore from (20) C_r is 237.2cm. The roll surface speed (cm/s) and roll rotational speed (rpm) is given by (21) and (22) respectively.

$R_{rpm} = (0.253) \times R_s$ (21)

$R_s = (3.953) \times R_{rpm}$ (22)

The roll speed in this application varies from 12cm/s (3rpm) to 16.6cm/s (4.2rpm). The voltage generated by tacho generator in response to the rotation of roll is given as:

$Vt = Kt\omega t$ (23)

Where Kt = constant which represent the physical construction like diameter and length of armature

ωt = angular velocity of rotating body to which tacho generator is attached.

The tacho generator selected in this application generates 50µV for 1rpm. Therefore tacho generator generates a voltage in the range from 150µV to 210µV and for every 0.1rpm tacho generator generates 5µV. A signal conditioning system is designed by using OrCAD pSpice software as shown in Fig.8. The purpose of signal conditioning system is to convert the 150µV to 210µV generated from tacho generator in the range 0 to 2.4V. Two operational amplifiers are used in signal conditioning. The operational amplifier U1A receives the output of tacho generator and the operational amplifier U1A is configured as a as a non-inverting amplifier and its voltage gain is given as:

$Av = 1 + (R6/R5)$ (24)

The values selected for R6 is 50KΩ and R5 is 5.6KΩ so the voltage gain of U1A is 10. The output of signal conditioning system which is proportional to the tacho generator output is feed to analog to digital converter. The ADC is calibrated to have a step size of 9.375mV. The digital output corresponding to different roll speed is given in Table 3.

Example III – The tacho generator generates 150μV if the roll speed is 12.0cm/s (3.0rpm). The output of signal conditioning system generates 1997mV and the simulated output of signal conditioning system is shown in Fig.9. The output of ADC is given by (18) and it comes to be 213 in decimal or D5H in hexadecimal.

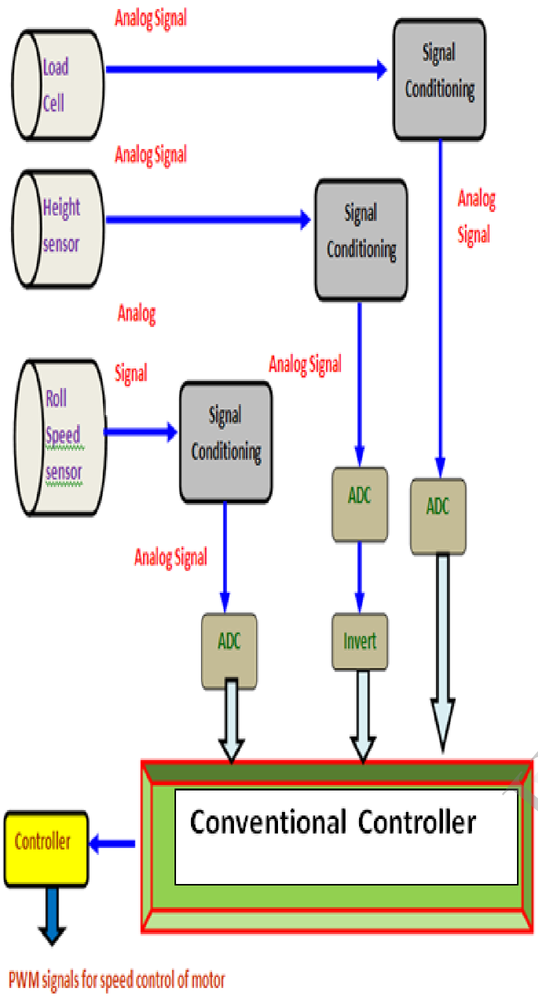

Fig.2. Conventional Controller to Maintain Cane Level

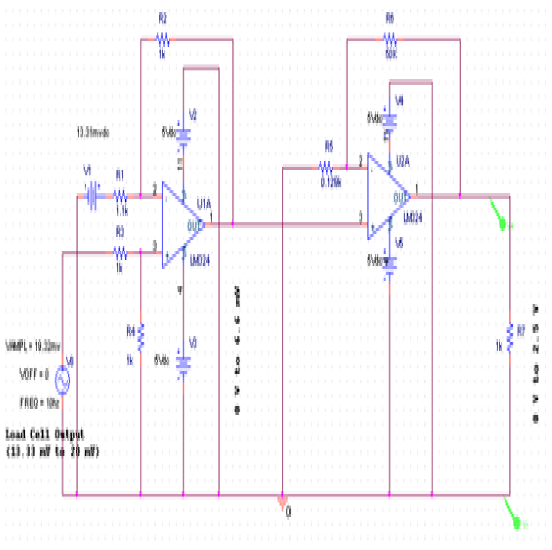

Fig.3. Cane Load Conditioning System

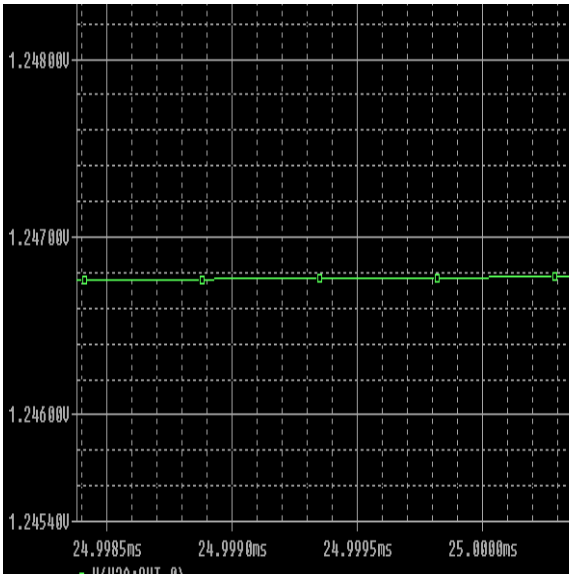

Fig.4. Output of Load Signal Conditioning System

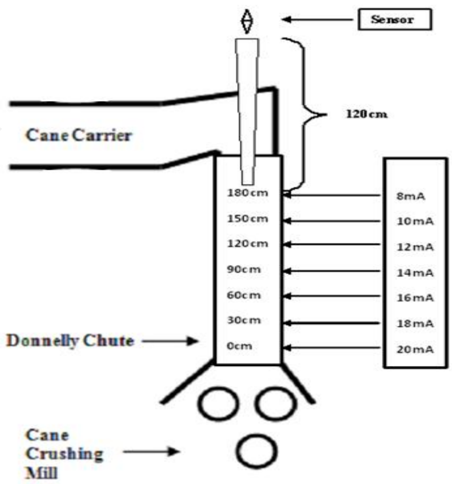

Fig.5. Cane Level Sensing Mechanism

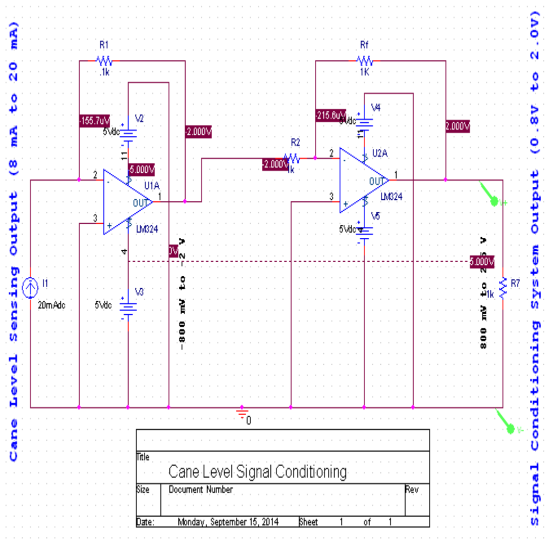

Fig.6. Cane Level Conditioning System

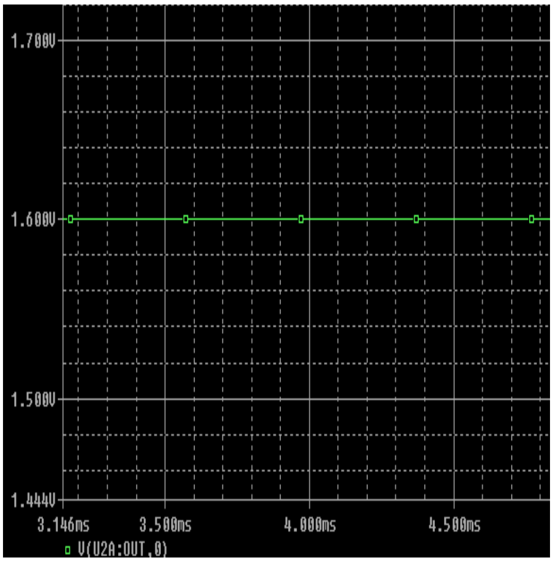

Fig.7. Output of Cane Level Sensing Signal Conditioning When Cane is at 60cm Level

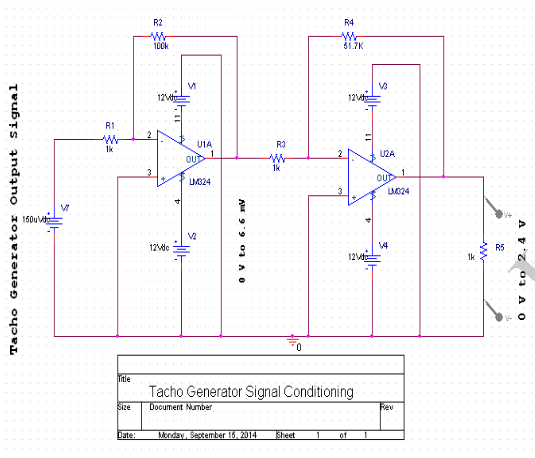

Fig.8. Roll Speed Conditioning System

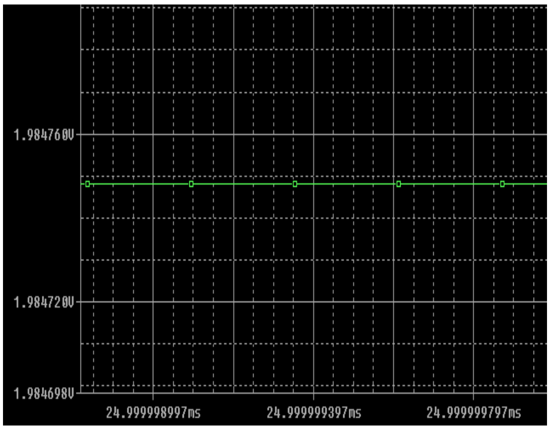

Fig.9. Output of Roll Speed Signal Conditioning System

Table. 1Digital Output Under Different Cane Load

Carrier Weight Including Cane (Kg)	Output of Load Cell (mV)	Output of Signal Conditioning System (V)	Output of ADC (Hex)
1000	13.33	0	00H
1050	13.99	0.261	1BH
1100	14.66	0.509	34H
1150	15.33	0.756	4DH
1200	15.99	1000	66H
1250	16.66	1250	80H
1300	17.32	1490	99H
1350	17.99	1770	B5H
1400	18.66	1980	CBH
1450	19.32	2230	E4H
1500	20.00	2500	FFH

Table 2. Digital Output During Different Cane Level

Cane Height (cm)	Output of Sensor (mA)	Output of Signal Conditioning System (V)	Output of ADC (Hex)	Inverse of ADC Output (Hex)
0	20.0	2.00	CDH	32H
30	18.0	1.80	B8H	47H
40	17.3	1.70	B1H	4EH
60	16.0	1.60	A4H	5BH
80	14.7	1.47	96H	69H
90	14.0	1.40	8FH	70H
100	13.3	1.33	88H	77H
120	12.0	1.20	7BH	84H
130	11.3	1.10	74H	8BH
150	10.0	1.00	66H	99H
180	8.0	0.80	52H	ADH

Table. 3 Digital Output During Different Roll Speed

Roll Speed (rpm)	Output of Tacho Generator (μV)	Output of Signal Conditioning System (V)	Output of ADC (Hex)
3	150	1997	D5
3.1	155	2023	D8
3.2	160	2049	DB
3.3	165	2074	DD
3.4	170	2100	E0
3.5	175	2126	E3
3.6	180	2152	E6
3.7	185	2178	E8
3.8	190	2203	EB
3.9	195	2229	EE

4	200	2255	F1
4.1	205	2281	F3
4.2	210	2307	F6

IV. CONVENTIONAL CONTROLLER DEVELOPMENT ALGORITHM

The variation in prepared cane quantity on rake carrier is in the range 500Kg to 1000Kg and this variation is sensed by load cell and the corresponding value is available in digital form. The prepared cane quantity is grouped in ten categories as shown in Table 4.

The variation in height of prepared cane in Donnelly chute is in the range 0cm to 180cm and this variation is sensed by light sensor and the corresponding value is available in digital form. The cane level in Donnelly chute is grouped in seven categories as shown in Table 5.

The variation in roll surface speed is in the range 12cm/s to 16.6cm/s and this variation is sensed by tacho generator and the corresponding value is available in digital form. The algorithm is developed for two ranges of roll surface speed as given below:

Group-I - When the roll speed is (≥12cm/s and ≤14.2cm/s).

Group-II - When the roll speed is (> 14.3cm/s and ≤ 16.6cm/s).

When the roll speed is (≥12cm/s and ≤14.2cm/s) and cane level is (≥ 0cm and < 30cm), (≥ 30cm and < 60cm) and (≥ 60cm and < 80cm) then the feed rate of cane is increased by 42%, 31% and 20% of flow rate respectively. When the roll speed is (> 14.3cm/s and ≤ 16.6cm/s) and cane level is (≥ 100cm and < 120cm), (≥ 120cm and < 150cm) and (≥ 150cm and ≤ 180cm) then the feed rate of cane is decreased by 42%, 31% and 20% of flow rate respectively. If the cane level is (≥ 80cm and < 100cm) then the feed rate should be equal to the flow rate. The flow chart of the methodology used to develop the VHDL code of conventional controller is shown in Fig.10. The speed of cane carrier under various conditions is given in Table 6 and Table 7.

A. Flow Rate Calculations for Group-I Roll Speed - When the roll speed is in the range of group-I then the average speed of roll is 13.2cm/s. The escribed volume (V_e) when the average surface speed (S) of roll is 13.2cm/s can be calculated from equation (9) and come to be $0.06m^3/s$. We can relate cane mass flow rate (Q_c), cane density (ρ_c) and escribed volume (V_e) by equation (11) as follows:

$$Q_c = \rho_c V_e$$

$$Q_c = 21.0Kg/s \qquad (25)$$

B. Flow Rate Calculations For Group-II Roll Speed - When the roll speed is in the range of group-II then the average speed of roll is 15.4cm/s. The escribed volume (V_e) when the average surface speed (S) of roll is 15.2cm/s can be calculated from equation (9) and come to be $0.07m^3/s$. We can relate cane mass flow rate (Q_c), cane density (ρ_c) and escribed volume (V_e) by equation (11) as follows:

$$Q_c = \rho_c V_e$$

$$Q_c = 24.5Kg/s \qquad (26)$$

Table. 4 Ten Categories of Prepared Cane Quantity

S.No.	Parameter		
	Name	Symbol	Range (Kg)
1	Super Low	SL	(≥ 500 and ≤ 549)
2	Ultra Low	UL	(≥ 550 and ≤ 599)
3	Extreme Low	EL	(≥ 600 and ≤ 649)
4	Very Low	VL	(≥ 650 and ≤ 699)
5	Low	L	(≥ 700 and ≤ 749)
6	Just Right	JR	(≥ 750 and ≤ 799)
7	High	H	(≥ 800 and ≤ 849)
8	Very High	VH	(≥ 850 and ≤ 899)
9	Extreme High	EH	(≥ 900 and ≤ 949)
10	Ultra High	UH	(≥ 950 and ≤ 1000)

Table. 5 Ten Categories of Prepared Cane Quantity

S.No.	Parameter		
	Name	Symbol	Range (cm)
1	Extreme Low	EL	(≥ 0 and < 30)
2	Very Low	VL	(≥ 30 and < 60)
3	Low	L	(≥ 60 and < 80
4	Just Right	JR	(≥ 80 and < 100)
5	High	H	(≥ 100 and < 120)
6	Very High	VH	(≥ 120 and < 150)
7	Extreme High	EH	(≥ 150 and ≤ 180)

C. Explanation of S. No. 1 of Table 6 - The cane weight is in the range from 500Kg to 549Kg and cane level in chute is ≥ 0cm and < 30cm. When the roll speed is ≥ 12cm/s and ≤14.2cm/s then flow rate of cane through the rolls is 21.0Kg/s as given in (11). According to the algorithm under these conditions the feed rate should be increased by 42% of flow rate and it comes to be 29.8Kg/s. The average weight of cane on carrier is considered as 525Kg. Therefore the carrier contains 0.656Kg in one cm of length. The carrier speed (cm/s) and rake carrier motor speed (rpm) is calculated from (27) and (28) respectively as:

Carrier Speed = (Feed Rate) / (Mass of cane in 1cm of carrier) (27)

Motor = (1.91) × (Carrier speed) (28)

So, from (27) and (28) the carrier speed and rake carrier motor speed is calculated as 45.4cm/s and 86.7rpm respectively.

D. Explanation of S. No. 1 of Table 7 - The cane weight is in the range from 500Kg to 549Kg and cane level in chute is ≥ 0cm and < 30cm. When the roll speed is > 14.2cm/s and ≤ 16.6cm/s then flow rate of cane through the rolls is 24.5Kg/s as given in equation (11). According to the algorithm under these conditions the feed rate should be increased by 42% of flow rate and it comes to be 34.8Kg/s.

The average weight of cane on carrier is considered as 525Kg. Therefore the carrier contains 0.656Kg in one cm of length. From (27) and (28) the carrier speed and the rake carrier motor speed is calculated as 53.0cm/s and 101.2rpm respectively.

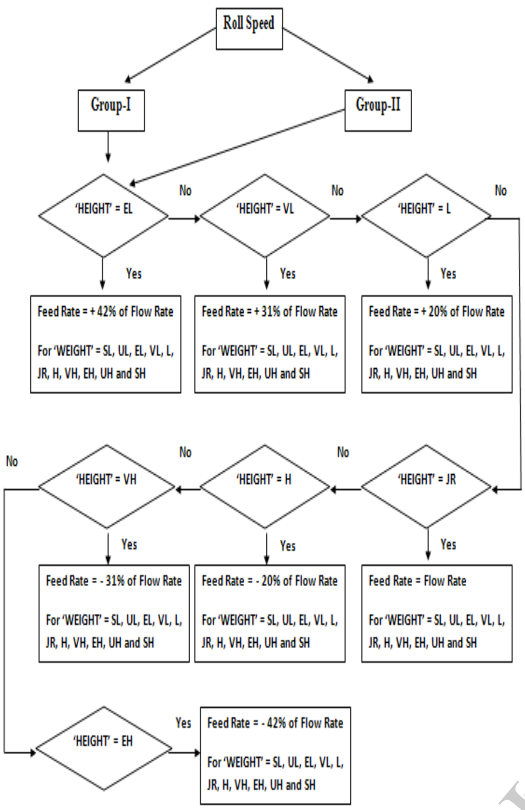

Fig.10. Conventional Controller Development Algorithm

Table 6. Conventional Controller Design Algorithm When the Roll Speed is (≥ 12.0cm/s and ≤ 14.2cm/s)

Cane weight (Kg)	Variation of Feed Rate (%)	Feed rate in (Kg/s)	Carrier Speed in (cm/s)	Motor Speed (rpm)
Cane Level ≥ 0cm and < 30cm (EL)				
500 to 549	+42%	29.8	45.4	86.7
550 to 599	+42%	29.8	41.4	79.1
600 to 649	+42%	29.8	38.2	73
650 to 699	+42%	29.8	35.3	67.4
700 to 749	+42%	29.8	32.9	62.8
750 to 799	+42%	29.8	30.8	58.8
800 to 849	+42%	29.8	28.9	55.2
850 to 899	+42%	29.8	27.2	52
900 to 949	+42%	29.8	25.8	49.3
950 to 1000	+42%	29.8	24.4	46.6
Cane Level ≥ 30cm and < 60cm (VL)				
500 to 549	+31%	27.5	41.9	80
550 to 599	+31%	27.5	38.2	73
600 to 649	+31%	27.5	35.2	67.2
650 to 699	+31%	27.5	32.6	62.3
700 to 749	+31%	27.5	30.4	58.1
750 to 799	+31%	27.5	28.4	54.2
800 to 849	+31%	27.5	26.7	51
850 to 899	+31%	27.5	25.1	47.9
900 to 949	+31%	27.5	23.8	45.5
950 to 1000	+31%	27.5	22.6	43.2
Cane Level ≥ 60cm and < 80cm (L)				
500 to 549	+20%	25.2	38.4	73.3
550 to 599	+20%	25.2	35	66.9
600 to 649	+20%	25.2	32.3	61.7
650 to 699	+20%	25.2	29.9	57.1
700 to 749	+20%	25.2	27.8	53.1
750 to 799	+20%	25.2	26	49.7
800 to 849	+20%	25.2	24.4	46.6
850 to 899	+20%	25.2	23	43.9
900 to 949	+20%	25.2	21.8	41.6
950 to 1000	+20%	25.2	20.7	39.5
Cane Level ≥ 80cm and < 100cm (JR)				
500 to 549	0%	21.0	32	61.1
550 to 599	0%	21.0	29.2	55.8
600 to 649	0%	21.0	26.9	51.4
650 to 699	0%	21.0	24.9	47.6
700 to 749	0%	21.0	23.2	44.3
750 to 799	0%	21.0	21.7	41.4
800 to 849	0%	21.0	20.4	39
850 to 899	0%	21.0	19.2	36.7

Contd....

Contd....

Table 6. Conventional Controller Design Algorithm When the Roll Speed is (≥ 12.0cm/s and ≤ 14.2cm/s)

Cane weight (Kg)	Variation of Feed Rate (%)	Feed rate in (Kg/s)	Carrier Speed in (cm/s)	Motor Speed (rpm)
900 to 949	0%	21.0	18.2	34.8
950 to 1000	0%	21.0	17.2	32.9
Cane Level ≥ 100cm and < 120cm (H)				
500 to 549	-20%	16.8	25.6	48.9
550 to 599	-20%	16.8	23.4	44.7
600 to 649	-20%	16.8	21.5	41.1
650 to 699	-20%	16.8	19.9	38
700 to 749	-20%	16.8	18.5	35.3
750 to 799	-20%	16.8	17.3	33
800 to 849	-20%	16.8	16.3	31.1

850 to 899	-20%	16.8	15.4	29.4
900 to 949	-20%	16.8	14.5	27.7
950 to 1000	-20%	16.8	13.8	26.4
Cane Level ≥ 120cm and < 150cm (VH)				
500 to 549	-31%	14.5	22.1	42.2
550 to 599	-31%	14.5	20.2	38.6
600 to 649	-31%	14.5	18.6	35.5
650 to 699	-31%	14.5	17.2	32.9
700 to 749	-31%	14.5	16	30.6
750 to 799	-31%	14.5	15	28.7
800 to 849	-31%	14.5	14.1	26.9
850 to 899	-31%	14.5	13.3	25.4
900 to 949	-31%	14.5	12.5	23.9
950 to 1000	-31%	14.5	11.9	22.7
Cane Level ≥ 150cm and ≤ 180cm (EH)				
500 to 549	-42%	12.2	18.6	35.5
550 to 599	-42%	12.2	17	32.5
600 to 649	-42%	12.2	15.6	29.8
650 to 699	-42%	12.2	14.5	27.7
700 to 749	-42%	12.2	13.5	25.8
750 to 799	-42%	12.2	12.6	24.1
800 to 849	-42%	12.2	11.8	22.5
850 to 899	-42%	12.2	11.2	21.4
900 to 949	-42%	12.2	10.6	20.2
950 to 1000	-42%	12.2	10	19.1

Table 7. Conventional Controller Design Algorithm When the Roll Speed is (> 14.2cm/s and ≤ 16.6cm/s)

Cane weight (Kg)	Variation of Feed Rate (%)	Feed rate in (Kg/s)	Carrier Speed in (cm/s)	Motor Speed (rpm)
Cane Level ≥ 0cm and < 30cm (EL)				
500 to 549	+42%	34.8	53	101.2
550 to 599	+42%	34.8	48.4	92.4
600 to 649	+42%	34.8	44.6	85.2
650 to 699	+42%	34.8	41.2	78.7
700 to 749	+42%	34.8	38.4	73.3
750 to 799	+42%	34.8	35.9	68.6
800 to 849	+42%	34.8	33.8	64.6
850 to 899	+42%	34.8	31.8	60.7
900 to 949	+42%	34.8	30.1	57.5
950 to 1000	+42%	34.8	28.5	54.4
Cane Level ≥ 30cm and < 60cm (VL)				
500 to 549	+31%	32.1	48.9	93.4
550 to 599	+31%	32.1	44.6	85.2
600 to 649	+31%	32.1	41.1	78.5
650 to 699	+31%	32.1	38	72.6
700 to 749	+31%	32.1	35.4	67.6
750 to 799	+31%	32.1	33.1	63.2
800 to 849	+31%	32.1	31.1	59.4
850 to 899	+31%	32.1	29.3	56
900 to 949	+31%	32.1	27.8	53.1
950 to 1000	+31%	32.1	26.3	50.2
Cane Level ≥ 60cm and < 80cm (L)				
500 to 549	+20%	29.4	44.8	85.6
550 to 599	+20%	29.4	40.9	78.1
600 to 649	+20%	29.4	37.6	71.8
650 to 699	+20%	29.4	34.8	66.5
700 to 749	+20%	29.4	32.5	62.1
750 to 799	+20%	29.4	30.3	57.9
800 to 849	+20%	29.4	28.5	54.4
850 to 899	+20%	29.4	26.9	51.4
900 to 949	+20%	29.4	25.4	48.5
950 to 1000	+20%	29.4	24.1	46
Cane Level ≥ 80cm and < 100cm (JR)				
500 to 549	0%	24.5	37.3	71.2
550 to 599	0%	24.5	34.1	65.1
600 to 649	0%	24.5	31.4	60
650 to 699	0%	24.5	29	55.4
700 to 749	0%	24.5	27	51.6
750 to 799	0%	24.5	25.3	48.3
800 to 849	0%	24.5	23.8	45.5
850 to 899	0%	24.5	22.4	42.8
900 to 949	0%	24.5	21.2	40.5
950 to 1000	0%	24.5	20.1	38.4
Cane Level ≥ 100cm and < 120cm (H)				
500 to 549	-20%	19.6	29.9	57.1
550 to 599	-20%	19.6	27.3	52.1

Contd....

Contd....

Table 7. Conventional Controller Design Algorithm When the Roll Speed is (> 14.2cm/s and ≤ 16.6cm/s)

Cane weight (Kg)	Variation of Feed Rate (%)	Feed rate in (Kg/s)	Carrier Speed in (cm/s)	Motor Speed (rpm)
600 to 649	-20%	19.6	25.1	47.9
650 to 699	-20%	19.6	23.2	44.3
700 to 749	-20%	19.6	21.6	41.3
750 to 799	-20%	19.6	20.2	38.6
800 to 849	-20%	19.6	19	36.3
850 to 899	-20%	19.6	17.9	34.2
900 to 949	-20%	19.6	17	32.5
950 to 1000	-20%	19.6	16.1	30.8
Cane Level ≥ 120cm and < 150cm (VH)				
500 to 549	-31%	16.9	25.8	49.3
550 to 599	-31%	16.9	23.5	44.9

600 to 649	-31%	16.9	21.6	41.3
650 to 699	-31%	16.9	20	38.2
700 to 749	-31%	16.9	18.7	35.7
750 to 799	-31%	16.9	17.4	33.2
800 to 849	-31%	16.9	16.4	31.3
850 to 899	-31%	16.9	15.4	29.4
900 to 949	-31%	16.9	14.6	27.9
950 to 1000	-31%	16.9	13.9	26.5
Cane Level ≥ 150cm and ≤ 180cm (EH)				
500 to 549	-42%	14.2	21.6	41.3
550 to 599	-42%	14.2	19.7	37.6
600 to 649	-42%	14.2	18.2	34.8
650 to 699	-42%	14.2	16.8	32.1
700 to 749	-42%	14.2	15.7	30
750 to 799	-42%	14.2	14.7	28.1
800 to 849	-42%	14.2	13.8	26.4
850 to 899	-42%	14.2	13	24.8
900 to 949	-42%	14.2	12.3	23.5
950 to 1000	-42%	14.2	11.6	22.2

V. IMPLEMENTATION OF CONVENTIONAL CONTROLLER IN FPGA

The block diagram of conventional controller for maintaining the level of cane during sugar making process is shown in Fig.1. We have used VHDL for the description of the proposed system. One advantage of using VHDL in system designing is its technology independency. Various steps involved in implementation of conventional for sugar mill are as follows:

A. VHDL Model [6] - There is many ways for writing VHDL Model viz. Behavior Model (it explains the functionality of the circuit) and Structure Model (it explains how the components are interconnected to each others). Behavior Model of the conventional controller is developed at VLSI Lab of Mody University of Science & Technology, Laxmangarh (India). The code for implementation of controller is written in VHDL and the experimental work is carried out on Anvyl FPGA development platform. Program Code is available with the authors.

B. Simulation [18] - After writing the VHDL Model of conventional controller the simulation is carried out. The functionality of the controller is verified from the waveform generated by the simulation tool. The simulation tool used for the simulation is Xilinx ISim. Simulated waveform of the conventional controller which is obtained after experiment is shown in Fig.11.

C. Synthesis [18] - Xilinx XST Tool is used for the purpose of synthesis. Technology schematic generated after synthesis is shown in Fig.12.

D. Lab Environment – Xilinx ISE Design Suite 14.5 is used for developing the VHDL model of conventional controller. Details of the selected FPGA used for the implementation of mill controller are as follows:

Make : Xilinx
Family : Spartan 6-LX45 FPGA
Device : XC6SLX45
Package : CSG484
Speed Grade : -3

The lab set-up for the implementation of conventional Controller for maintaining the cane level during sugar making process shown in Fig.13.

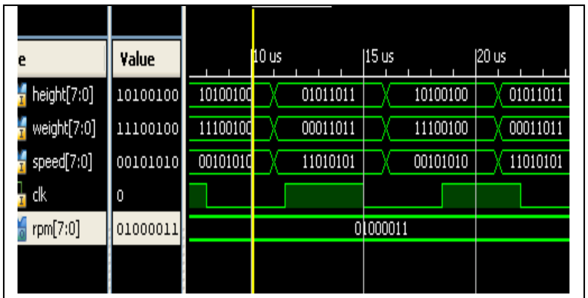

Fig.11. Hight = 60cm, Weight = 550Kg and Roll Speed = 12.0cm/s then Motor rpm = 67rpm

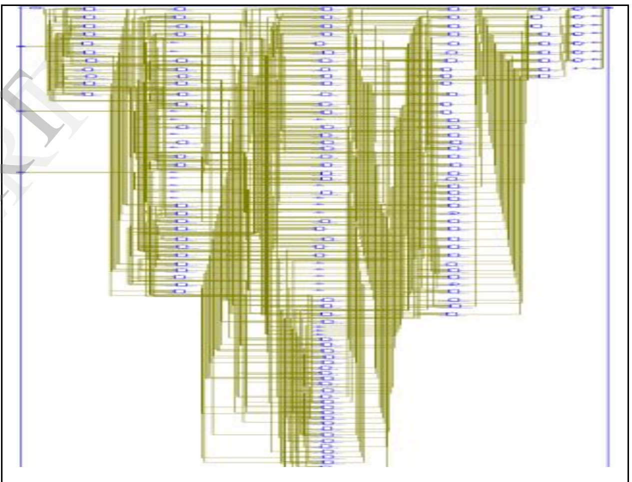

Fig.12. Technology Schematic of Conventional Controller

Fig.13. Lab Set-Up for Implementation of Conventional Controller for Maintaining Cane Level

V. RESULT AND DISCUSSION

A. Device Utilization Report generated after synthesis of conventional controller is given below:

Optimization Goal	: Speed
Selected Device	: 6slx45csg484-3
Number of Slices	: 190 out of 27288
Number of bonded IOBs	: 33 out of 320
IOB Flip Flops	: 7
TIMING REPORT	
Speed Grade	: -5
Minimum period	: 10.71ns
(2.88ns logic, 7.83ns route)	
(26.9% logic, 73.1% route)	

The critical delay of conventional controller is 10.71ns. 26.9% of critical delay i.e. 2.88ns is utilized in logic part of the design and 73.1% of critical delay i.e. 7.83ns is utilized in routing part of design. The maximum operating frequency of the implemented design is 93MHz.

When the cane level in Donnelly chute is at height 60cm, cane quantity on carrier is 550Kg and roll speed is 12.0cm/s then from the design algorithm of conventional controller Table 6 the speed of motor to run cane carrier should be 67rpm (43H). This condition is shown in Fig. 11.

B. Conventional controller is simulated for the duration of 210 seconds for six different cases. The sampling period is 10 seconds i.e. after every 10 seconds the value of cane level in chute, quantity of cane on rake carrier and the roll speed is sampled.

In Case-I and Case-II the cane level and cane weight on carrier at the start of simulation is assumed to be 90cm and 750Kg and the roll speed at the start of simulation is 15cm/s for Case-I and 15.4cm/s for Case-II. The roll speed variation is less in Case-I and in Case-II it varies at the time of each sample. The simulation result is given in Table 8 and Table 9 for Case-I and Case-II respectively.

In Case-III and Case-IV the cane level and cane weight on carrier at the start of simulation is assumed to be 0cm and 750Kg and the roll speed at the start of simulation is 15cm/s for Case-I and 15.4cm/s for Case-II. The roll speed variation is less in Case-III and in Case-IV it varies at the time of each sample. The simulation result is given in Table 10 and Table 11 for Case-III and Case-IV respectively.

In Case-V and Case-VI the cane level and cane weight on carrier at the start of simulation is assumed to be 180cm and 750Kg and the roll speed at the start of simulation is 15cm/s for Case-I and 15.4cm/s for Case-II. The roll speed variation is less in Case-V and in Case-VI it varies at the time of each sample. The simulation result is given in Table 12 and Table 13 for Case-V and Case-VI respectively.

The results of Case-I to Case-VI are shown in Fig.11 to Fig.16. The comparison between Case-I to Case-VI is given in Table 14.

VI CONCLUSION

The comparison between Case-I to Case-VI gives rise following conclusions:

(i) When the cane level is at 90cm at the start of simulation (Case-I and Case-II) then conventional controller performed better if there is less variation in roll speed.

(ii) When the cane level is at 0cm at the start of simulation (Case-III and Case-IV) then conventional controller performed better if there is less variation in roll speed.

(iii) When the cane level is at 180cm at the start of simulation (Case-V and Case-VI) then conventional controller for Case-VI (when roll speed varies during each sampling) shows better result in maintaining the level of cane between 85cm-95cm but for remaining two parameters conventional controller performed better if there is less variation in roll speed.

Finally, it can be concluded that a three input conventional controller perform better if there is less frequent variations in roll speed and if there is more variation in roll speed then its performance degraded.

VII FUTURE SCOPE

Since the input variables are non-linear therefore it is very difficult to design a mathematical model for the controller for maintaining the cane level in sugar making process.

Under these conditions the authors are working towards the development of three input fuzzy controller and expect some better results as compared to conventional controller.

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Table 8. Case-I Cane Level is at 90cm and Less Variation in Roll Speed

Parameters: Time (s)	Parameters: Roll speed (cm/s)	Cane Level (cm)	Cane Weight (Kg)	Motor Speed (rpm)	Carrier Speed (cm/s)	Cane in Carrier (Kg/cm)	Feed Rate (Kg/s)	Data for next sampling: Kg	Data for next sampling: cm	Level for next sample (cm)
0	15	90	750	48	25.1	0.938	23.5	-5	-1.8	88.2
10		88.2	729	52	27.2	0.911	24.8	+8	+2.9	91.1
20		91.1	792	48	25.1	0.990	24.8	+8	+2.9	94.0
30		94.0	908	41	21.5	1.135	24.4	+4	+1.4	95.4
40	12.6	95.4	965	33	17.3	1.206	20.9	+7	+2.5	97.9
50		97.9	720	44	23.0	0.900	20.7	+5	+1.8	99.7
60		99.7	760	41	21.5	0.950	20.4	+2	+0.7	100.4
70		100.4	790	33	17.3	0.988	17.1	-31	-11.1	89.3
80		89.3	820	39	20.4	1.025	20.9	+7	+2.5	91.8
90	16.2	91.8	555	65	34.0	0.694	23.6	-24	-8.6	85.2
100		85.2	609	60	31.4	0.761	23.9	-21	-7.5	77.7
110		77.7	578	78	40.8	0.723	29.5	+35	+12.5	90.2
120		90.2	598	65	34.0	0.748	25.4	-6	-2.1	88.1
130		88.1	700	52	27.2	0.875	23.8	-22	-7.9	80.2
140		80.2	679	55	28.8	0.849	24.5	-15	-5.4	74.8
150	15.4	74.8	800	54	28.3	1.000	28.3	+36	+12.9	87.7
160		87.7	845	46	24.1	1.056	25.4	+7	+2.5	90.2
170		90.2	835	46	24.1	1.044	25.2	+5	+1.8	93.0
180		93.0	874	43	22.5	1.093	24.6	-1	-0.4	92.6
190		92.6	900	41	21.5	1.125	24.2	-5	-1.8	90.8
200		90.8	924	41	21.5	1.155	24.8	+1	+0.4	91.2

Table 9. Case-II Cane Level is at 90cm and Roll Speed Vary during Each Sample

Parameters: Time (s)	Parameters: Roll speed (cm/s)	Cane Level (cm)	Cane Weight (Kg)	Motor Speed (rpm)	Carrier Speed (cm/s)	Cane In Carrier (Kg/cm)	Feed Rate (Kg/s)	Data for next sampling: Kg	Data for next sampling: cm	Level for next sample (cm)
0	15.4	90	750	48	25.1	0.938	23.5	-9	-3.2	86.8
10	15.8	86.8	729	52	27.2	0.911	24.8	+1	+0.4	87.2
20	15.0	87.2	792	48	25.1	0.990	24.8	+1	+0.4	87.6
30	16.2	87.6	908	41	21.5	1.135	24.4	-3	-1.1	86.5
40	16.6	86.5	965	38	19.9	1.206	24.0	-7	-2.5	84.0
50	13.4	84.0	720	44	23.0	0.900	20.7	-8	-2.9	81.1
60	13.8	81.1	760	41	21.5	0.950	20.4	-17	-6.1	75.0
70	13.4	75.0	790	50	26.2	0.988	25.9	+44	+15.7	90.7
80	15.4	90.7	820	46	24.1	1.025	24.7	0	0	90.7
90	16.2	90.7	555	65	34.0	0.694	23.6	-24	-8.6	82.1
100	13.0	82.1	609	51	26.7	0.761	20.3	-57	-20.4	61.7
110	14.3	61.7	578	78	40.8	0.723	29.5	+66	+23.6	85.4
120	14.6	85.4	598	65	34.0	0.748	25.4	+20	+7.1	92.5
130	12.3	92.5	700	44	23.0	0.875	20.1	+4	+1.4	93.5
140	12.6	93.5	679	48	25.1	0.849	21.3	+11	+3.9	97.4
150	15.4	97.4	800	46	24.1	1.000	24.1	-6	-2.1	95.3
160	12.0	95.3	845	39	20.4	1.056	21.5	+23	+8.2	103.5
170	14.3	103.5	835	46	24.1	1.044	25.2	+23	+8.2	111.7
180	14.6	111.7	874	29	15.2	1.093	27.5	+41	+14.6	127.9
190	15.0	127.9	900	28	14.7	1.125	16.5	-75	-26.8	101.1
200	15.4	101.1	924	33	17.3	1.155	20	-47	-16.8	84.3

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Table 10. Case-III Cane Level is at 0cm and Less Variation in Roll Speed

Parameters		Cane Level (cm)	Cane Weight (Kg)	Motor Speed (rpm)	Carrier Speed (cm/s)	Cane in Carrier (Kg/cm)	Feed Rate (Kg/s)	Data for next sampling		Level for next sample (cm)
Time (s)	Roll speed (cm/s)							Kg	cm	
0	15	0	750	69	36.1	0.938	33.9	+99	+35.4	35.4
10		35.4	729	68	35.6	0.911	32.4	+84	+30.0	65.4
20		65.4	792	58	30.4	0.990	30.1	+61	+21.8	87.2
30		87.2	908	41	21.5	1.135	24.4	+4	+1.4	88.6
40	12.6	88.6	965	33	17.3	1.206	20.9	+7	+2.5	91.1
50		91.1	720	44	23.0	0.900	20.7	+5	+1.8	92.9
60		92.9	760	41	21.5	0.950	20.4	+2	+0.7	93.6
70		93.6	790	41	21.5	0.988	21.2	+10	+3.6	97.2
80		97.2	820	39	20.4	1.025	20.9	+7	+2.5	99.7
90	16.2	99.7	555	65	34.0	0.694	23.6	-24	-8.6	90.1
100		90.1	609	60	31.4	0.761	23.9	-21	-7.5	82.6
110		82.6	578	65	34.0	0.723	24.6	-14	-5	77.6
120		77.6	598	78	40.8	0.748	30.5	+45	+16.1	93.7
130		93.7	700	52	27.2	0.875	23.8	-22	-7.9	85.8
140		85.8	679	55	28.8	0.849	24.5	-15	-5.4	80.4
150	15.4	80.4	800	46	24.1	1.000	24.1	-6	-2.1	78.3
160		78.3	845	54	28.3	1.056	29.9	+52	+18.6	94.9
170		94.9	835	46	24.1	1.044	25.2	+5	+1.8	96.7
180		96.7	874	43	22.5	1.093	24.6	-1	-0.4	96.3
190		96.3	900	41	21.5	1.125	24.2	-5	-1.8	94.5
200		94.5	924	41	21.5	1.155	24.8	+1	+0.4	94.9

Table 11. Case-IV Cane Level is at 0cm and Roll Speed Vary during Each Sample

Parameters		Cane Level (cm)	Cane Weight (Kg)	Motor Speed (rpm)	Carrier Speed (cm/s)	Cane In Carrier (Kg/cm)	Feed Rate (Kg/s)	Data for next sampling		Level for next sample (cm)
Time (s)	Roll speed (cm/s)							Kg	cm	
0	15.4	0	750	69	36.1	0.938	33.9	+92	+32.9	32.9
10	15.8	32.9	729	68	35.6	0.911	32.4	+71	+25.4	58.3
20	15.0	58.3	792	63	33.0	0.990	32.7	+87	+31.1	89.4
30	16.2	89.4	908	41	21.5	1.135	24.4	-16	-5.7	83.7
40	16.6	83.7	965	38	19.9	1.206	23.9	-27	-9.6	74.1
50	13.4	74.1	720	53	27.7	0.900	24.9	+34	+12.1	86.2
60	13.8	86.2	760	41	21.5	0.950	20.4	-17	-6.1	80.1
70	13.4	80.1	790	41	21.5	0.988	21.2	-3	-1.1	79.0
80	15.4	79.0	820	54	28.3	1.025	29.0	+43	+15.4	94.4
90	16.2	94.4	555	65	34.0	0.694	23.6	-24	-8.6	85.8
100	13.0	85.8	609	51	26.7	0.761	20.3	-5	-1.8	84.0
110	14.3	84.0	578	65	34.0	0.723	24.6	+17	+6.1	90.1
120	14.6	90.1	598	65	34.0	0.748	25.4	+20	+7.1	97.2
130	12.3	97.2	700	44	23.0	0.875	20.1	+4	+1.4	98.6
140	12.6	98.6	679	48	25.1	0.849	21.3	+11	+3.9	102.5
150	15.4	102.5	800	46	24.1	1.000	24.1	-6	-2.1	100.4
160	12.0	100.4	845	31	16.2	1.056	17.1	-21	-7.5	92.9
170	14.3	92.9	835	46	24.1	1.044	25.2	+23	+8.2	101.1
180	14.6	101.1	874	34	17.8	1.093	19.5	-39	-13.9	87.2
190	15.0	87.2	900	41	21.5	1.125	24.2	+2	+0.7	87.9
200	15.4	87.9	924	41	21.5	1.155	24.8	+1	+0.4	88.3

Table 12. Case-V Cane Level is at 180cm and Less Variation in Roll Speed

Parameters		Cane Level (cm)	Cane Weight (Kg)	Motor Speed (rpm)	Carrier Speed (cm/s)	Cane in Carrier (Kg/cm)	Feed Rate (Kg/s)	Data for next sampling		Level for next sample (cm)
Time (s)	Roll speed (cm/s)							Kg	cm	
0	15	180	750	28	14.7	0.938	13.8	-102	-36.4	143.6
10		143.6	729	36	18.8	0.911	17.1	-69	-24.6	119.0
20		119.0	792	39	20.4	0.990	20.2	-38	-13.6	105.4
30		105.4	908	33	17.3	1.135	19.6	-44	-15.7	89.7
40	12.6	89.7	965	33	17.3	1.206	20.9	+7	+2.5	92.2
50		92.2	720	44	23.0	0.900	20.7	+5	+1.8	94.0
60		94.0	760	41	21.5	0.950	20.4	+2	+0.7	94.7
70		94.7	790	41	21.5	0.988	21.2	+10	+3.6	98.3
80		98.3	820	39	20.4	1.025	20.9	+7	+2.5	100.8
90	16.2	100.8	555	52	27.2	0.694	18.9	-71	-25.4	75.4
100		75.4	609	72	37.7	0.761	28.7	+27	+9.6	85.0
110		85.0	578	65	34.0	0.723	24.6	-14	-5.0	80.0
120		80.0	598	65	34.0	0.748	25.4	-6	-2.1	77.9
130		77.9	700	62	32.5	0.875	28.4	+24	+8.6	86.3
140		86.3	679	55	28.8	0.849	24.5	-15	-5.4	80.9
150	15.4	80.9	800	46	24.1	1.000	24.1	-6	-2.1	78.8
160		78.8	845	54	28.3	1.056	29.9	+52	+18.6	97.4
170		97.4	835	46	24.1	1.044	25.2	+5	+1.8	99.2
180		99.2	874	43	22.5	1.093	24.6	-1	-0.4	98.8
190		98.8	900	41	21.5	1.125	24.2	-5	-1.8	97.0
200		97.0	924	41	21.5	1.155	24.8	+1	+0.4	97.4

Table 13. Case-VI Cane Level is at 180cm and Roll Speed Vary during Each Sample

Parameters		Cane Level (cm)	Cane Weight (Kg)	Motor Speed (rpm)	Carrier Speed (cm/s)	Cane In Carrier (Kg/cm)	Feed Rate (Kg/s)	Data for next sampling		Level for next sample (cm)
Time (s)	Roll speed (cm/s)							Kg	cm	
0	15.4	180	750	28	14.7	0.938	13.8	-102	-36.4	143.6
10	15.8	143.6	729	36	18.4	0.911	16.8	-85	-30.4	113.2
20	15.0	113.2	792	39	20.4	0.990	20.2	-38	-13.6	99.6
30	16.2	99.6	908	41	21.5	1.135	24.4	-16	-5.7	93.9
40	16.6	93.9	965	38	19.9	1.206	24.0	-26	-9.3	84.6
50	13.4	84.6	720	44	23.0	0.900	20.7	-8	-2.9	81.7
60	13.8	81.7	760	41	21.5	0.950	20.4	-17	-6.1	75.6
70	13.4	75.6	790	50	26.2	0.988	25.9	+44	+15.7	91.3
80	15.4	91.3	820	46	24.1	1.025	24.7	0	0	91.3
90	16.2	91.3	555	65	34.0	0.694	23.6	-24	-8.6	82.7
100	13.0	82.7	609	51	26.7	0.761	20.3	-5	-1.8	80.9
110	14.3	80.9	578	43	22.5	0.723	16.3	-66	-23.6	57.3
120	14.6	57.3	598	85	44.5	0.748	33.3	+99	+35.4	92.7
130	12.3	92.7	700	44	23.0	0.875	20.1	+4	+1.4	94.1
140	12.6	94.1	679	48	25.1	0.849	21.3	+11	+3.9	98.0
150	15.4	98.0	800	46	24.1	1.000	24.1	-6	-2.1	95.9
160	12.0	95.9	845	39	20.4	1.056	21.5	+23	+8.2	104.1
170	14.3	104.1	835	36	18.8	1.044	19.6	-33	-11.8	92.3
180	14.6	92.3	874	43	22.5	1.093	24.6	+12	+4.3	96.6
190	15.0	96.6	900	41	21.5	1.125	24.2	+2	+0.7	97.3
200	15.4	97.3	924	41	21.5	1.155	24.8	+1	+0.4	97.7

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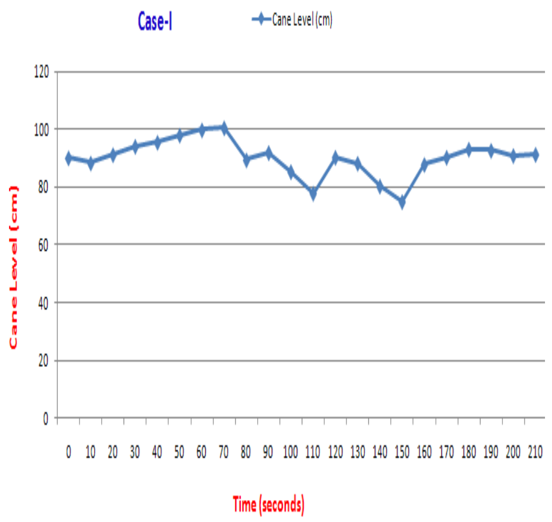

Fig.11. Case-I

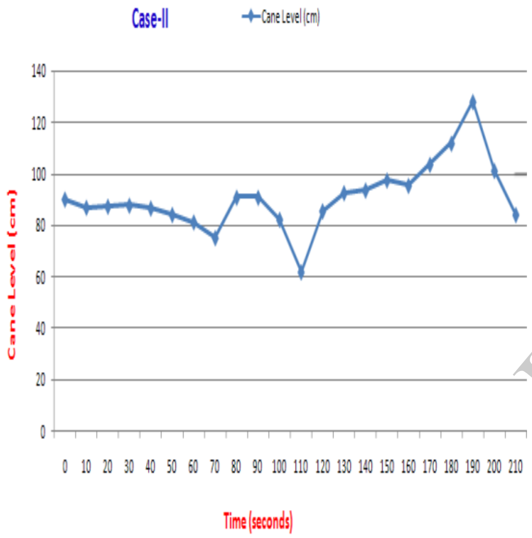

Fig.12. Case-II

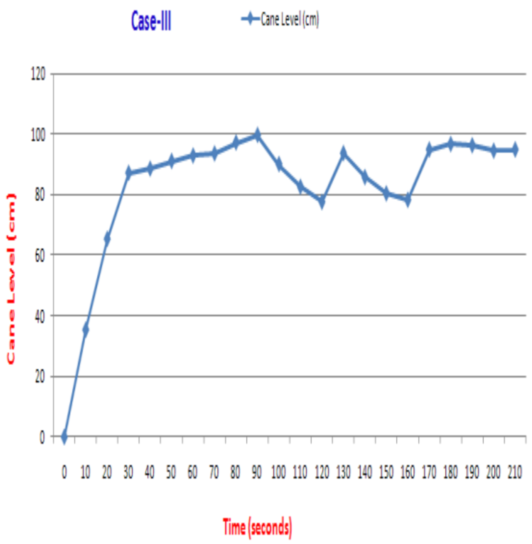

Fig.13. Case-III

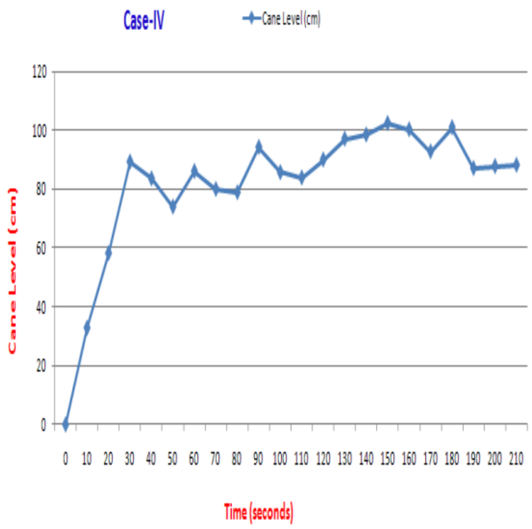

Fig.14. Case-IV

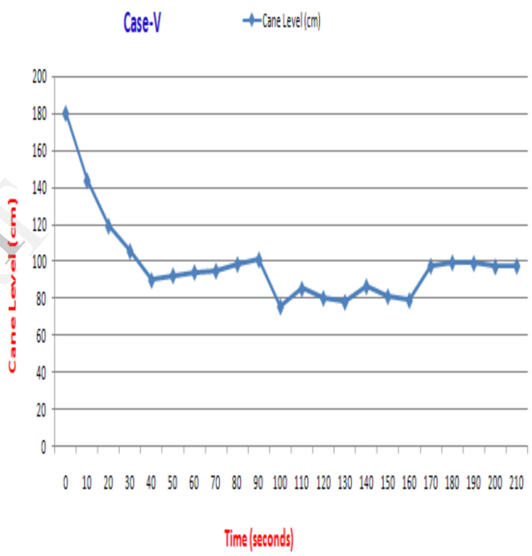

Fig.15. Case-V

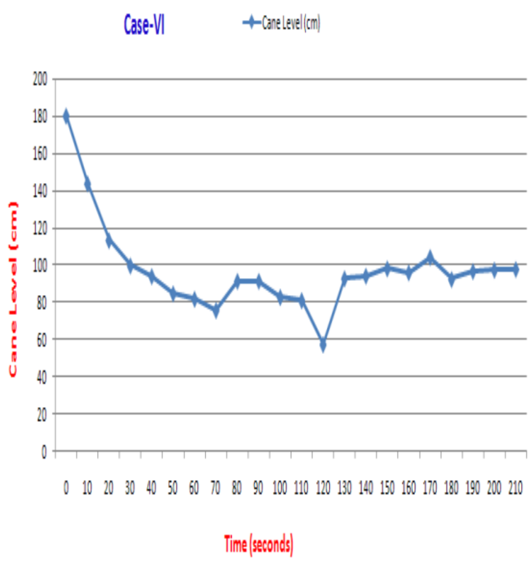

Fig.16. Case-VI

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Table 14 Comparison between Case-I to Case-VI of Conventional Controller				
	Cane Level in Between 85cm-95cm (% Time)	Time Required to Reach Cane Level at 90cm (sec)	Lowest Level of Cane in chute (cm)	Highest Level of Cane in Chute (cm)
Case-I	64.3	NA	74.8	100.4
Case-II	45.8	NA	61.7	103.5
Case-III	45.8	45.6	NA	99.7
Case-IV	37.6	86.1	NA	102.5
Case-V	22.6	39.8	75.4	NA
Case-VI	26.6	44.2	57.3	NA

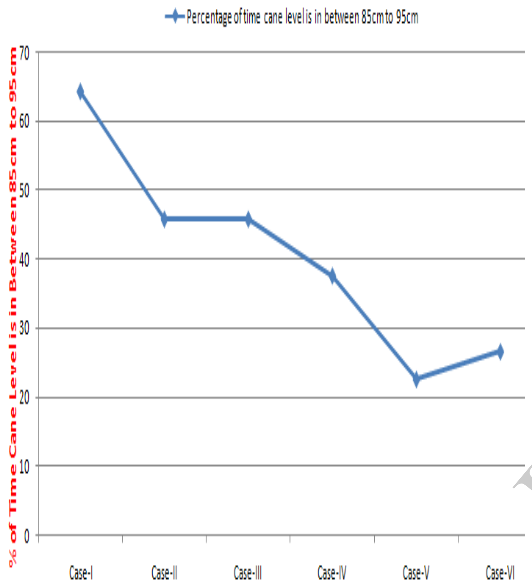

Fig.17. % of Time Cane Level is Between 85-95cm

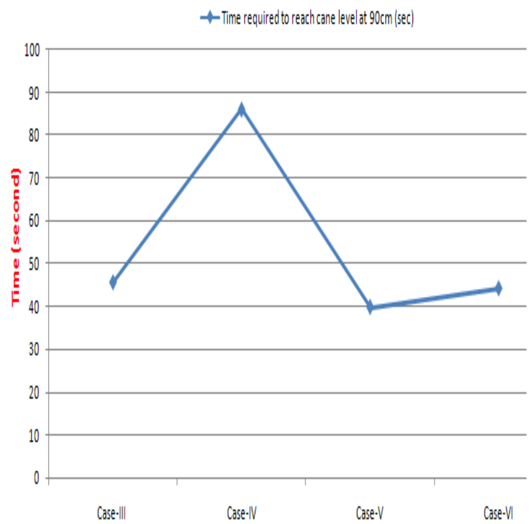

Fig.18. Time Required to Reach Cane Level at 90cm

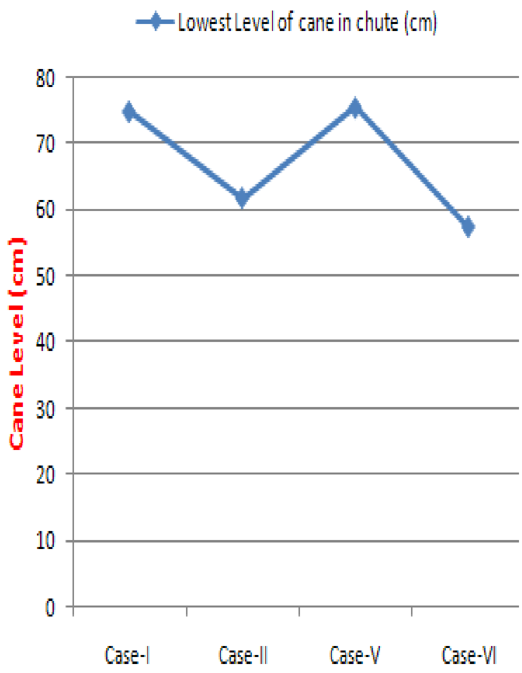

Fig.19. Lowest Level of Cane

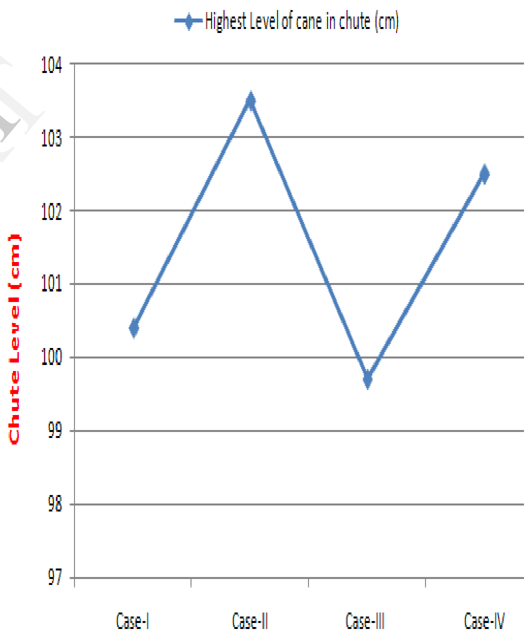

Fig.20. Highest Level of Cane

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