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An Efficient Approach for Shear Behavior Definition of Plant Stalk

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Abstract**—**The information of the impact cutting behavior of plants stalk plays an important role in the design and fabrication of plants cutting equipment. It is difficult to investigate a theoretical method for defining cutting properties of plants stalks because the cutting process is complex. Thus, it is necessary to set up an experimental approach to determine cutting parameters for a single stalk. To measure the shear force, shear energy and shear strength of plant stalk, a special impact cutting tester was fabricated. It was similar to an Izod impact cutting tester for metals but a cutting blade and data acquisition system were attached to the end of pendulum's arm. The apparatus was included four strain gages and a digital indicator to show the real-time cutting force of plant stalk. To measure the shear force and also testing the apparatus, two plants' stalks, like buxus and privet, were selected. The samples (buxus and privet stalks) were cut under impact cutting process at four loading rates 1, 2, 3 and 4 m.s^{-1} and three internodes fifth, tenth and fifteenth by the apparatus. At buxus cutting analysis: the minimum value of cutting energy was obtained at fifth internode and loading rate 4 m.s^{-1} and the maximum value of shear energy was obtained at fifteenth internode and loading rate 1 m.s^{-1}. At privet cutting analysis: the minimum value of shear consumption energy was obtained at fifth internode and loading rate: 4 m.s^{-1} and the maximum value of shear energy was obtained at fifteenth internode and loading rate: 1 m.s^{-1}. The statistical analysis at both plants showed that the increase of impact cutting speed would decrease the shear consumption energy and shear strength. In two scenarios, the results showed that with increase the cutting speed, shear force would decrease.

Keywords**—**Buxus, privet, impact cutting, shear energy.

I. INTRODUCTION

THE information of the impact cutting properties of plants stalk, like shear force, shear consumption energy, and resistance to stem cutting, are necessary for design and fabrication of proper trimmer equipment's. In recent years, several researches have been conducted to determine the quasi-static cutting properties of plants stem [1], [2]. But it seems that there are a few published works relating to the determination of impact cutting properties of plants stem. In practice and real cutting, the cutting of plants stalk is not a quasi-static cutting but it is a dynamic process [2].

The impact cutting process by a rapidly moving cutting blade is similar to dynamic process and in impact cutting, with increasing loading rate, the primary compression of outer layer was decreased and also plastic behavior of plant stalk material and the shear consumption energy decreased [1].

Stem cutting like some of agricultural applications is very slowly, repetitive and occasionally dangerous for labors and current trimmer machines are not suitable and accountable. Nowadays, operators are exposed to the dangerous effects of arms and body vibrations that occur by plant stem trimmer machines. To reduce dangerous effects of vibration on operator's arms and also to increase the speed and quality of plant cutting, the design and fabrication of proper trimmer equipment is necessary. Thus, by determining the mechanical properties of plants stalk such as shear force, shear consumption energy and stem resistance to cutting, a suitable cutting machine can be designed. Therefore the objective of this study was to introduce a method to measure the impact cutting behavior of plants stalk.

Yiljep and Mohammed reported the high correlation between knife velocity, cutting energy requirement and cutting efficiency. Also they estimated the minimum cutting energy requirements for 20 and 120 mm stalk cutting height, 7.87 and 12.55 N.m respectively, at corresponding knife velocities of 2.91 and 3.54 m.s^{-1} [2]. Tabatabaee and Borgheie studied shear cutting of four rice variety and stated that the dynamic shearing strength decreased from 234.4 to 137.4 Kpa with an increase in blade cutting angle speed from 0.6 to 1.5 m.s^{-1} [3]. Taghijarah et al. found that loading rate had a significant effect on the shear strength and specific shearing energy of the stalk and reported that with increasing loading rate, the shear strength and specific shearing energy was increased [4]. Dange et al. studied on the cutting energy and force required for the pigeon pea crops, and they observed that the cutting energy and cutting force were directly proportional to cross-sectional area and moisture content at the time of harvesting of pigeon pea crop [5]. Taghijarah et al. investigated that the ultimate stress and specific cutting energy decreased with an increase in size of cutting section in sugarcane stalks [6]. Mathanker et al. investigated that specific cutting energy increased with an increase in sugarcane stalks shear velocity [7]. Azadbakht et al. studied impact cutting of canola and reported that at blade velocity 2.64 m.s^{-1}, the maximum and minimum cutting energy was measured 1.1 KJ in 25.5 % w.b. moisture content at 10 cm cutting height and 0.76 KJ in 11.6% w.b. moisture content and 30 cm cutting height respectively at the time of cutting [8].

II. MATERIAL AND METHODS

Definition of shear properties of plant stalk such as shear force is not possible by theoretical methods. To solve the problem an electro-mechanical apparatus was designed and fabricated [9]. The apparatus was consisted a pendulum arm

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and a special shear blade was attached to the end of pendulum's arm (the blade sharpened angel and oblique angle were 23 and 60 degree respectively). Fig. 1 shows the schematic diagram of pendulum arm [2]. A data acquisition system was attached to pendulum arm and it included four strain gages and a digital indicator to show the real-time shear force. Four strain gages were contacted to each other by Wheatstone bridge circuit and were mounted on two sides of pendulum.

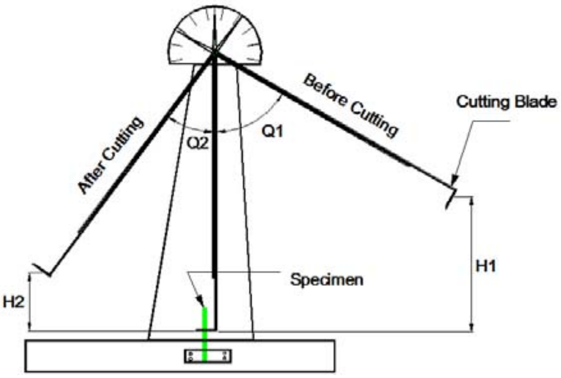

Fig. 1 Schematic diagram of pendulum arm position

By the principle of conservation of potential energy to kinetic energy, the pendulum when released from φ_1 is expected to swing to the other side of equilibrium line and deflection through an angle φ_2 and due to frictional losses in the parts and air resistance, φ_2 is normally less than φ_1. To delete the parts friction and air resistance effects, the losses energy was computed by pendulum oscillation at loading rates without any cutting and was detracted of main energy values.

For calibration of data acquisition system, pendulum was released from distinct distance and the blade was contacted to strong sample. After contacting, the pendulum has been stopped and kinetic energy is converted to heat energy. The pendulum momentum is equal to multiplication of pendulum weight and contact speed or area under strain gage output volt versus time curve. Finally, the output volts of strain gages were converted to impact force by the usage of conversion ratio (Cr) which was calculated as in (1) [10]:

$$\int F.dt = m.V \;\; and \;\; F \propto Cr.\nu \Rightarrow \int Cr.\nu.dt = m.V \Rightarrow Cr = {m.V}\Big/{\int \nu.dt} \tag{1}$$

where F: Contact force (N); m: Pendulum weight (N); ν: Output volt (V); V: Blade velocity of pendulum at contact time (m.s^{-1}); Cr: Conversion ratio.

When the pendulum is normally released from one side of the equilibrium position by an angular deflection (φ_1), it is swung to the other side of equilibrium line and deflected through an angle (φ_2). To obtain the different velocities, the pendulum arm was released from different positions in the vertical plane on the upswing. The blade velocity and cutting energy in contact position to specimen were calculated by (2) and (3), respectively.

$$E = W_t R(cos\varphi_2 - cos\varphi_1) \tag{2}$$

$$V = \sqrt{[\frac{2w_t R(1-cos\varphi_1)}{I}] \times L} \tag{3}$$

where: E: Shear consumption energy (J); φ_2: Maximum angular displacement of pendulum from vertical line after cutting (deg); φ_1: Maximum angular displacement of pendulum from vertical line before cutting (deg); W_t: Total weight of the pendulum including arm, load cell and cutting blade weight (N); R: Distance of the center of gravity of the pendulum from the axis of rotation (m); V: Blade velocity in the lowest position of pendulum (m.s^{-1}); I: Mass moment of inertia of the pendulum about the axis of rotation (Kg. m^2); L: Distance of the blade from the axis of rotation (m).

The release angels (φ_1) selected for this case are: 85, 60, 40 and 20 degrees and cutting velocities (4, 3, 2 and 1 m.s^{-1}) were calculated related to these angels. After calibration, the impact shear force was applied to the buxus samples by releasing the pendulum arm in the testing machine up to the sample failure. The real-time applied force and cutting time were measured by data acquisition system.

For testing of the apparatus, a series of experimental tests were conducted to measure the shear force, shear strength and shear energy consumption of buxus and privet stem at impact cutting process as a function of a shear velocity and stalk region. The buxus and privet used for the present study were obtained from green space of College of Abouraihan, Pakdasht, Iran. The buxus and privet stalk samples were collected at the last month of the spring season in 2016 and the ASAE (2005) was used to measure the average moisture content of buxus stalk [11]. The initial moisture content of the buxus and privet samples was measured to be 72% and 58% on wet base respectively (Figs. 2 and 3).

The buxus and privet stalk diameter decrease towards to the top of the plant stalks, which means it shows different physico-mechanical properties at different heights of stalk due to the variable cross section area [12], [13]. The cross section area of buxus stalk is similar to oval, it was equally divided into three regions downward from the stem terminal bud: (a) fifth internode position with small diameter ranges from 3.17 to 3.96 mm and large diameter ranges from 4.15 to 4.85 mm, (b) tenth internode position with small diameter ranges from 4.05 to 4.72 mm and large diameter ranges from 5.12 to 5.88 mm and (c) fifteenth internode position with small diameter ranges from 4.45 to 5.05 mm and large diameter ranges from 5.35 to 5.88 mm. Similar to buxus stalk, the cross section area of privet stalk is similar to oval, it was equally divided into three regions downward from the stem terminal bud: (a) fifth internode position with small diameter range of 3.44 to 4.56 mm and large diameter range of 4.38 to 5.11 mm, (b) tenth internode position with small diameter range of 3.90 to 5.11 mm and large diameter range of 4.87 to 5.98 mm and (c) fifteenth internode position with small diameter range of 4.72

to 5.85 mm and large diameter range of 5.44 to 6.88 mm

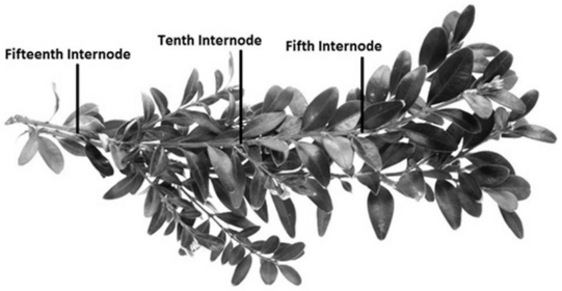

Fig. 2 Diagram of buxus stalk and three selected internode positions

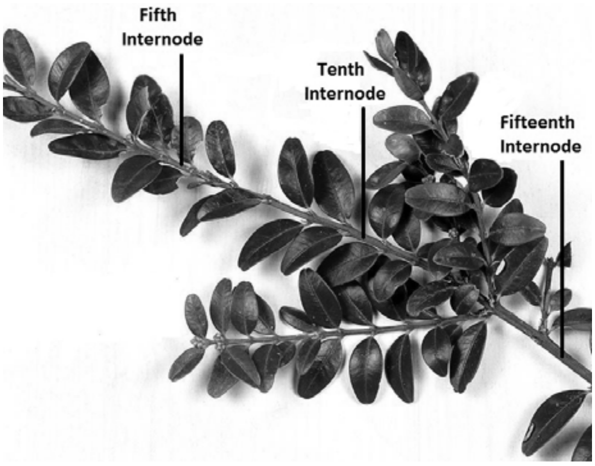

Fig. 3 Diagram of privet stalk and three selected internode positions

This study was planned as a completely randomized block design. The experimental tests were conducted with eight replications in each treatment and finally the collected data were analyzed using analysis of variance (ANOVA) and the means were separated by 5% and 1% probability levels by using Duncan's multiple range test in SPSS (version 17, SPSS Inc., USA) software.

III. RESULTS AND DISCUSSIONS

This study was undertaken to design and fabricate an apparatus to measurement the impact cutting properties of plants stalk. Some information as shear force, shear consumption energy and shear strength regarding to impact cutting of plants stalk is needed to design of proper trimmer machines. Finally the apparatus was tested by determination of shear force, shear consumption energy and shear strength of buxus and privet stalk at impact cutting process. The test parameters were loading rates (1, 2, 3 and 4 m.s^{-1}) and internodes of stalks (fifth, tenth and fifteenth). The results of two analyses are presented in the following sections:

A. Test Analysis of Buxus Stalk

Fig. 4 shows the interaction effects of loading rate and internode position on buxus shear energy requirement. In all regions in this figure, the shear energy decreased poly-nominally with the increase of loading rate and its value varied from 3.19 to 16.4 J, 3.3 to 18.3 J and 5.9 to 19.6 J for the fifth, tenth and fifteenth internode respectively at different loading rate. As demonstrated in Fig. 4, the cutting energy increased with the increase of loading rate for all the region of buxus stalk.

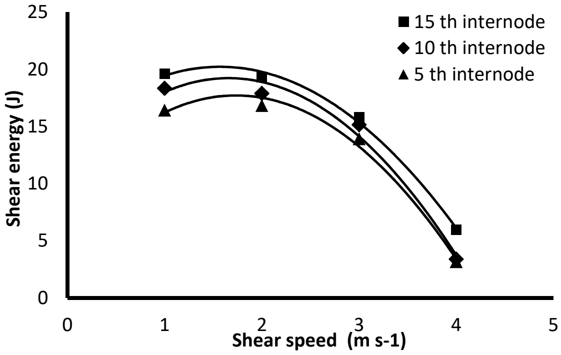

Fig. 4 Relationship between shear energy and shear speed at different internode positions

Fig. 5 shows the interaction effect of loading rate and internode position on buxus shear strength. In all regions and internode positions of Fig. 4, the shear strength decreased polynomial with the increase of loading rate. The highest strength shear was obtained as 1.03 Mpa for fifteenth internode of stalk at the speed rate of 2 m.s^{-1} and the lowest value was obtained as 0.14 Mpa for fifth internode at the speed rate of 4 m.s^{-1}.

B. Test Analysis of Privet Stalk

The interaction effect of loading rate and internode position on the shear consumption energy is presented in Fig**.** 6. As demonstrated in Fig**.** 6, the cutting energy strongly decreased with increase in the loading rate for all regions of privet stalk. The highest cutting energy was obtained 28.60 J for the fifteenth internode of stalk at the speed rate of 1 m/s and the lowest value was obtained 3.19 J for the fifth internode at the speed rate of 4 m/s. In all regions of Fig**.** 5, the shear energy decreased polynomial shape with an increase of loading rate and its value varied from 3.19 to 19.22 J for fifth internode, 5.53 to 24.05 J for tenth internode and 11.07 to 28.60 J for fifteenth internode at different loading rate.

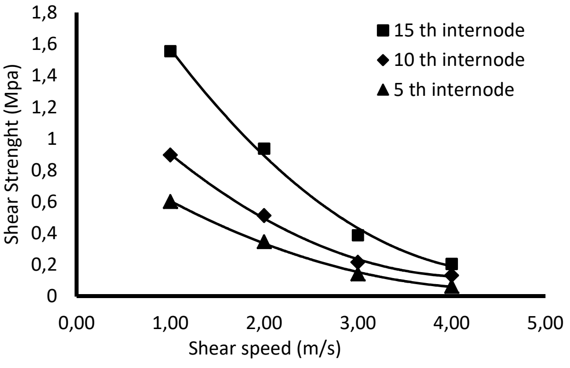

Fig. 5 Relationship between shear strength and shear speed at different internode positions

The models fitted to the data using the regression techniques showed that the cutting energy decreased polynomial shape with increasing the loading rate for all stalk regions. These effects of loading rate and internode position on shear consumption energy were also reported by [14] for forge crops, [15] for sorghum stalk and [3] for rice stem.

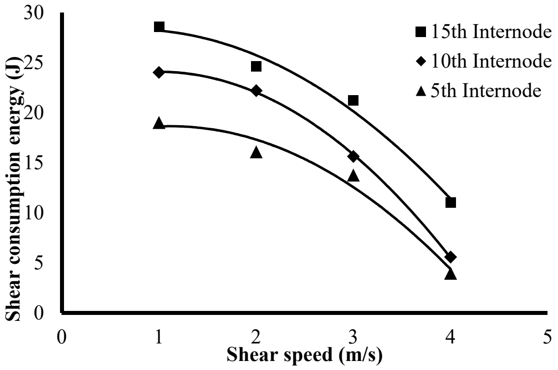

Fig. 6 Relationship between shear consumption energy and shear speed at different internod positions

Fig. 7 shows the interaction effect of loading rate and internode position on privet stalk shear strength. The highest value of shear strength was obtained as 2.53 Mpa for the fifteenth internode at the speed rate of 1 m/s and the lowest value was obtained as 0.21 Mpa for the fifth internode at the speed rate of 4 m/s. These effects of loading rate and internode position on shear strength were also reported by [2] for sorghum stalk, [3] for rice stem, [5] for pigeon pea stem and [8] for canola stem.

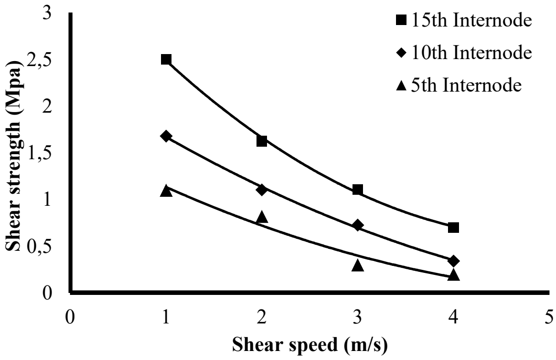

Fig. 7 Relationship between shear strength and shear speed at different internod positions

IV. Conclusions

In this study, the effects of shearing loading rate of buxus and privet stem on shear strength and shear energy were investigated according to the internode positions of stem. Results indicated that an increase in shearing loading rate led to a decrease in the shear strength and the shear consumption energy. The reduction proportion of energy consumption at blade velocity of 1 to 4 $m.s^{-1}$ was about 3.3. It showed that the shear consumption energy in low speed level of impact cutting was 3.3 times higher than that in high speed level cutting. Additionally, results showed that the shear consumption energy decreased upward from fifteenth to fifth internode position. Meanwhile, the increment proportion of shear consumption energy at internode position 15^{th} to 5^{th} was about 25%. By considering to shearing results, shear strength strongly decreased with an increase of loading rate and was upward from fifteenth to fifth internode position. The reduction proportion of shear strength at blade velocity of 1 to 4 $m.s^{-1}$ is about 40 and the increment proportion of shear strength at internode position 15^{th} to 5^{th} is about 2.5. Moreover, the impact shear process was similar to dynamic process. In impact cutting, as the increase of loading rate, the primary compression decreased as a result's inertia and plastic behavior of buxus stalk material and the shear consumption energy decreased [1].

The impact cutting results demonstrated that an increase in shearing loading rate led to a decrease in the shear strength and the shear consumption energy. The reduction proportion of privet stalk cutting consumption energy at shear velocity of 4 m/s to 1 m/s is about 2.5 at fifth internode, 2.4 at tenth internode and 3.4 at fifth internode of privet stalk. It shows that the shear consumption energy in low speed level of impact cutting is around 2 to 3.5 times higher than high speed level cutting. The reduction proportion of privet stalk resistance to cutting at shear velocity variation from 4 m/s to 1 m/s is about 1.2 at fifth internode, 1.3 at tenth internode and 1.5 at fifth internode of privet stalk. It shows the shear strength in low speed level of impact cutting is around 1 to 1.5 times higher than high speed level cutting. Also in impact cutting, results showed that the shear consumption energy and shear strength increased from fifth to fifteenth internode position. Meanwhile the mean increment proportions of shear consumption energy and shear strength at fifteenth internode position to fifth internode position are 1.76 and 2.27 respectively.

The plant cutting process has two stages: at the first stage the cutting blade involves preliminary compaction of stalk outer layer and the second stage the motion of the cutting blade in the stalk material cuts the stalk. The outer layer material of stalk is compressed up to a spatial amount until the cutting resistance of privet stalk is overcome. So the increase of deformation outer layer of plants stalk is the important reason for increase the shear consumption energy and shear strength. It seems that the variation of the static cutting characteristics is a function of the layer deformation of plant stalk and with increasing preliminary compaction amount, the proportion of outer layer deformation work is increased and the shear consumption energy is increased [17].

In practice, the cutting of plant stalk is not a quasi-static cutting but it is a dynamic process. The impact cutting process by a rapidly moving cutting blade is similar to dynamic process and in impact cutting, with increasing loading rate, the primary compression of outer layer was decreased as a result's inertia and plastic behavior of plant stalk material and the shear consumption energy decreased. It is clear that, in plant stalk impact cutting, with increasing the cutting velocity the shear energy requirements decreased considerably, and the

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proportion of useful cutting work increased [1]. At the other hand, the cutting consumption energy and cutting resistance of plant stalk at both cutting methods correspond to variations in the texture, primarily in the proportions of fibrous and ligneous of stalk material. The thickness and texture of stalks also vary as functions of height, and so the shear consumption energy and shear resistance to cutting also depend on the location of the cut and internode position. So in both of quasi-static and impact cutting, all parameters are highest at lower region of stalk [1].

The models fitted to the data using the regression techniques showed that the cutting energy and shear strength increased polynomial shape with increasing the loading rate for all stalk regions. Based on Figs. 3-6, it is clear that the character of the changes in the shear consumption energy and shear strength properties was best expressed by a quadratic polynomial equation at both of quasi-static and impact cutting methods. These sort of shear consumption energy and shear strength changes were also reported for winter rape stalk by Skubisz [18]. Based on figures, the shear consumption energy and shear strength at both of quasi-static and impact cutting were significantly affected by internod position and these values increased towards to lower region of privet and buxus stalks because of more cross-section diameter and more accumulation mature fibers in the lower region of the stalks [19].

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