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DYNAMIC MECHANISM AND STRESS TO DETACH UNSHIU MANDARIAN

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Abstract

Using the fruit-branch system of Unshiu Mandarian, the dynamic detachment test was done by the exciting apparatus in our laboratory. The various component forces and moment produced by fruit motion were measured and the combined stresses applied to the abscission zone that were required to detach the fruit were calculated. Also, a high speed 8 mm cinema camera was used to observe the process of fruit detachment and the dynamic mechanism to detach the fruit from the acscission zone without any fruit damages was discussed.

In order to detach Unshiu Mandarian from its abscission zone within short time, it was important to occur the pendlum motion of the fruit supported by the abscission zone and to increase the bending and torsional stresses applied to the zone. This motion became more active at such a time that the exciting velocity became the highest. That is, the detachment of the fruit was dependent on the exciting velocity and independent of the exciting acceleration.

The repeated combined stresses required to detach Unshiu Mandarian were more than 90 kgf/cm²(8.8 MPa) in maximum principal stress and more than 45 kgf/cm² (4.4 MPa) in maximum shearing stress, whose value was about half of the maximum principal stress. When these stresses applied to the abscission zone, the fruit detachment was occurred in repeated number of less than 10 times and in time of less than 1 second. The exciting velocities required to generate these stresses were more than 2.5 m/sec in the case of exciting the fruit-branch system horizontally, and more than 1.5 m/sec in the case of exciting the system in the 45 degree direction from the horizontal.

Generally, the exciting direction of having vertical component was more effective to detach fruits but in this case, it had a tendency to increase the detachment type that the rind of fruit was broken.

Introduction

The method of harvesting fruits by mechanical operation has been studied from over 30 years ago and recently, the technical feasibility of picking fruits from a tree with robotic arm has been developed; robotic fruit harvester of having single arm system have been developed in France, America¹⁾ and Japan³⁾.

For robotic tree-fruit harvesting to succeed, the developers of these harvesters must consider the constrains imposed by both the work and economic environments in which the systems will be operated.²⁾ In case of robotic harvesting, high quality of harvested products will be expected but high harvest performance will not be expected because of not so fast average pick cycle time. For processed fruit prodution, it seems that conventional harvesting systems, such as mechanical shake-catch system or air shaker system, are superior with their high working efficiencies.

The author has attached greater importance of mass removal of fruits and has tried to investigate the possibility of detaching fruits by dynamic force without any fruit damages. If it is possible, the high performance fruit harvester which is combained robotic harvester with conventional harvester will be perfected in future.

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The objective of this fundametal study is to clarify the fruit detachment mechanism and stress produced by dynamic motion of fruit. In this report, about 200 pieces of fruit-branch systems of Unshiu Mandarian, whose production was the highest of all Japanese fruits, were used as experimental materials and the tests to detach fruits from branches were done by using an exciting apparatus. The various component forces and moment that were produced by fruit motion during excitation were measured to calculate the detachment stress. Also, the dynamic mechanism of detaching fruits from their abscission zones was discussed.

Experimental Apparatus and Procedure

1. Excitng Apparatus and Transducer

The test apparatus for oscillating fruit-branch system is shown in Fig. 1. $^{5)}$ The slider crank mechanism powered by a 2. 2 Kw motor with infinitely variable speeds was used as a vibrator, so that the slider was able to move in frequency range from 2 Hz to 35 Hz and in amplitude range from 5 mm to 50 mm by changing the eccentric distance of the crank pin. To minimize the transient response of slider motion, a magnetic clutch was installed in its transmission system. This apparatus could excite fruit-branch system in the straight lines of horizontal, vertical and 45 deg. motions.

The expected forces and moments which are produced by fruite motion are contructed, as shown in Fig.2. Referring to Fig.2, the resultant force P_{xyz} is divided into three component forces P_x , P_y and P_z , and if these component forces and torsional moment T are measured individually, the combined stress to be applied to the abscission zone (point O) can be calculated.

To measure these forces and moment, the transducer which had twelve strain gauges affixed on an aluminum pipe was made, as shown in Fig.3.⁵⁾ A, B, C1 and C2 shown in Fig.3 indicate the strain gauges to measure P_z , T, P_x and P_y respectively (referring to Fig.2). This transducer was made as small and lightly as possible, so that its weight was about 20 grf.

2. Experimental Procedure

In this experiment, about 200 pieces of fruitgranch systems of Unshiu Mandarian(Hayashi-kei) were used as materials. A single model of fruitbranch system was cut from the tree and clamped to the vibrator after the transducer was sandwiched between the branch and fruit, as shown in Fig.1(b) and Fig.3. Therefore, the length of test material





Fig. 1. Exciting apparatus used in test and clamping state of fruit - branch system

became 40 mm longer than that of original one.

The experiment of fruit detachment was performed in the following conditions; changing frequencies in eight steps of 4.5, 6, 7.5, 9, 12, 15, 18 and 21 Hz, and amplitudes in four steps of 15, 25, 40 and 50mm. The forces and moment detected by the transducer were recorded on a magnetic tape recorder



Fig. 2. Force and moment produced by fruit motion



Fig. 3. Transducer to measure forces and moment

with other necessary data. Also, 8mm cinema camera whose filming speed was 74 frames per second was used to observe fruit motion.

The sizes and weights of all fruits used in the tests were measured. Their average values were as follows ; longer diameter of fruit D_i =70mm, shorter diameter of fruit Ds =44mm, diameter of abscission zone da =4.6mm and weight of fruit W=120.5grf, where the shape of fruit and the section of abscission zone were assumed as ellipsoid and circle respectively.

Experimental Results and Discussion

1. Detachment Mechanism of Fruit

The removal of Unshiu Mandarian produced by the dynamic motion of fruit were divided into some detachment types⁶⁾. The rind of the fruit is very weak and apt to break around the sepal when dynamic forces are applied to the system, as shown in Fig.4. Therefore, in order to detach the fruit from its abscission zone, it is important to select the proper exciting combination of frequency, amplitude and direction of excitation. Generally, vertical excitation facilitates to detach fruits more than horizontal excitation but the former increases the rate of broken-rind-detachment more than the latter.

Two examples of oscillogram data, in which the various component forces and moment produced by fruit motion were recorded under two exciting



Fig. 4. Detachment types of Unshiu Mandarian

conditions of horizontal and 45deg. derections, are shown in Fig. 5. Each notation of f, a, W and da in this figure represents respectively frequency(Hz), amplitude(mm), weight of fruit(grf) and diameter of abscission zone(mm). Fig. 5 indicated that the periods of the forces and moment produced by the periodic motion of fruit agreed approximately with the period of forced vibration and the fruits were detached from their abscission zone in times of 0.18 and 0.13 second after the start of exciting. Fig. 6 shows the motion pictures of the same fruit of shown in Fig. 5. After two or three cycles of fruit motion were repeated, the detachment of fruit was occurred, at that time, the pendulum motion of the fruit supported by its abscission zone was maximized. Namely, in order to detach fruits from its abscission zone without tearing its rind, the pendulum fruit motion supported by its abscission zone should be occurred (Fig. 6), at that time, the bending and tortional moment applied to its abscission zone was increased.

The phase angle of the slider in which the fruit detachments were generated was investigated and shown in Fig. 7 and 8. In these figures, the scales of



Fig. 5. Two examples of oscillgram data to detach fruits



a) Fruit motion at horizontal exciting



b) Fruit motion at 45 deg. exciting Fig. 6. Motion pictures of fruit detachment

velocity and acceleration are shown, as an example, by the values calculated from frequecy of 12 Hz and the phase angle of the slider is represented by the crank rotation angle, as $TDC = 0^{\circ}$ and also, "repeated number" means the cycle number of fruit motion to be repeated before fruit detachment.

In Fig. 7, whose test was held under the condition of horizontal exciting with amplitude of 40mm, about 40 pieces of fruits were removed in the phase angle regions of $60^{\circ} \sim 140^{\circ}$ (pattern A) and $275^{\circ} \sim$ 350° (Pattern B) and these regions of phase angle were the approximate position where the velocity of slider became the fastest. The simular result was obtained in Fig. 8, whose experiment was done under the condition of 45 deg. exciting with amplitude of 25mm. The phase angle of slider in which about 60 pieces of fruits were detached, was in regious of $30^{\circ} \sim 75^{\circ}$ (Pattern A) and $260^{\circ} \sim 310^{\circ}$ (Pattern B), at that time, the velocity of slider had the almost maximum value.

These experimental results make it clear that the



Fig. 7. Phase angele to generate fruit detachment at horizontal exciting

detachment of fruit is dependent on the exciting velocity and independent of the exciting acceleration. That is, the fruit detachment are generated in such a case where the exciting velocity have the maximum value.

2. Detachment Stress of Fruit

When the fruit is detached from the abscission zone, three stresses, which are mormal stress (σ_N) produced by Pz, bending stress (σ_B) produced by resultant Pxy of Px and Py, and shearing stress (τ_T) produced by T (referring to Fig. 2), are acted simultaneously on the section of abscission zone.

These stresses are calculated by the following equations,

$$\sigma_{\rm N} = \frac{4 \rm l P z \rm l}{\pi \, d a^2} \qquad \sigma_{\rm B} = \frac{16 \rm D s P x \rm y}{\pi \, d a^3} \qquad \tau_{\rm T} = \frac{16 \rm l T \rm l}{\pi \, d a^3}$$

where, Ds = shorter diameter of fruit

da = diameter of abscission zone $Pxy = \sqrt{Px^2 + Py^2}$

then, maximum principal stress (σ max) and



Fig. 8. Phase angele to generate fruit detachment at 45 deg. exciting

maximum shering stress (τ max) are discribed into the following equations⁴⁾,

$$\sigma \max = \frac{1}{2} (\sigma_{\rm N} + \sigma_{\rm B}) + \frac{1}{2} \sqrt{4 \tau_{\rm T}^2 + (\sigma_{\rm N} + \sigma_{\rm B})^2}$$

$$\tau \max = \frac{1}{2} \sqrt{4 \tau_{\rm T}^2 + (\sigma_{\rm N} + \sigma_{\rm B})^2}$$

These stresses were calculated from the all experimental data. As an example, the values calculated from the data of Fig. 5 (b) are shown in Fig. 9. There were some theories that the fruit detachment was mainly generated by the normal stress applied to detaching section but this result of Fig.9 (a) indecates that the increase of the bending and tortional stess is more advantageous than the increase of normal stress to detach the fruit from its abscission zone without tearing the rind. Namely, for the effective detachment of fruit without any fruit damages, it is necessary to generate the pendulum fruit motion supported by the abscission zone (point 0 in Fig. 2) and to increase the bending and shearing stresses applied to the zone, as was stated previously.

In Fig. 9 (b) that showed the changes of combined stresses acted on the abscission zone untill the detachment of fruit, σ max and τ max reached the maximum values without detaching the fruit at the time of about 0.08 second after the start of excitation and the perfect fruit detachment was occurred at the next process that their stresses were increasing. Parhaps, it was assumed that the removal of the abscission zone began to generate at the first process of having the largest stresses. The value of τ max became about half of σ max value in all fruits used in the test.

An example of the case that the fruit detachment did not occur was shown in Fig. 10, in which Fig. (a) and (b) showed the changes of individual stress and combined stress respectively. In such a condition that the maximum value of σ max was less than 80 kgf/cm² (7.8MPa) or that of τ max was less than 40 kgf/cm² (3.9 MPa), the detachment of Unshiu Mandarian could not occur, even if the repeated number became more than 30 times.

From the result of the detachment test using about 200 pieces of Unshiu Mandarian, the maximum principal stresses applied to their abscission zone were calculated and plotted in Fig. 11, whose scale of x-axis was expressed by the exciting velocity and the combination of friquency and amplitude by which this velocity was generated. The value of the maximum principal stress(σ max) required to detach the fruit was more than 90 kgf/cm²(8.8MPa), about 45 kgf/cm²(4.4MPa) as to the maximum shearing stress (τ max), and when this stress acted on the abscission zone, the fruit detachment would be occurred in repeated number of less than 10 times or



Fig. 9. An example of the stress acted on abscission zone with fruit detachment (f=12Hz, a=25mm, 45deg. exciting)



Fig. 10. An example of the stress acted on abscission zone without fruit detachment (f=6 Hz, a=25mm, 45deg. exciting)



Fig. 11. Relationship between exciting velocity and maximum principal stress acted on abscission zone

in time of less than 1 second. The exciting velocities required to generate these stresses were more than 2.5m/sec in case of exciting the fruit-branch system horizontally and more than 1.5m/sec in case of exciting it in the 45 degree derection from the horizontal. As was stated previously, the exciting direction of having vertical compenent is apt to detach the fruit more than that of only horizontal component but the former may increase the rate of broken-rind-detachment. Specially, it must be prevented to excite the fruit-branch system of Unshiu Mandarian vertically.

This paper offered the technical information of how to detach Unshiu Mandarian by the dynamic force without tearing the fruit-rind but in order to succeed such a harvesting method, the catching frame system must be equiped with the allover harvest-system in the same matter as conventional fruit-harvesters. The author has alreadey developed the small-sized and self-propelled catiching frame⁷) and is going to develope the automatic control mechaism to shift the catching surface to an arbitrary location in future.

References

- 1) HARRELL, R., P. D. ADSIT and D. C. SLANGHTER : ASAE Paper, 85(3550), 1-15, 1985.
- 2) HARRELL, R.: Trans. ASAE, 30(2), 298-304, 1987.
- KAWAMURA, N., K. NAMIKAWA, K. FUJIURA and M. URA: Proceed. Vehicle Automation Symp., 35-42, 1984 (in Japanese).
- 4) Онота, Т. : Strength of Materials, 11, 151-157, Sankaido, Tokyo, 1971 (in Japanese).
- 5) YAMAMOTO, H. and N. KAWAMURA : Japan. Soc. Agric. Machinery, 38(1), 53-62, 1976 (in Japanese with English summary).
- YAMAMOTO, H. : Japan. Soc. Agric. Machinery, 37 (4), 577-586, 1976 (in Japanese with English summary).
- 7) YAMAMOTO, H. and N. YAMAMOTO : Sci. Rep. Fac. Agric. Kobe Univ., 16(2), 467-475, 1985 (in Japanese with English summary).

Η.ΥΑΜΑΜΟΤΟ

温州ミカンの動的離脱機構と離脱応力

山本博昭

要 約

温州ミカンの果実-結果枝系を対象にし、加振装置を用いた動的離脱試験を行った。果実の運動によって離層に作 用する各種分力及びモーメントを測定し、離脱に必要な組合せ応力を明らかにすると共に、果皮損傷をなくし、離層か ら果実を離脱させるための最適離脱機構について考察した。離脱のプロセスを観察するため、高速度8ミリカメラによ る撮影も行った。

温州ミカンを離層から短時間で離脱させるためには、離層を支点とする果実の振子運動を励起させ、離層に作用する 曲げ応力とねじりによるせん断応力を増大させる必要がある。これからの運動は、振動速度が最大となる時点で励起さ れ、即ち、果実の離脱は加振速度に依存し、加振加速度には関係しないことが明かとなった。

温州ミカンを離層から脱離させるための動的、繰り返し、組合せ応力は、最大主応力で約90kgf/cm²以上、最大せん断 応力では、その半分の45kgf/cm²が必要である。この時、離脱するまでの応力繰り返し数は10回以下、時間にすると1秒 以内で果実は落下する。これらの応力値が確保されるための加振速度は、果実-結果枝系が水平方向に加振される場合 で、2.5m/sec以上、垂直方向の成分を有する、例えば45°方向加振の場合で、1.5m/sec以上が必要となる。

一般に、垂直成分を有する方向で、果実-結果枝系を加振する方が、果実の離脱は容易となるが、皮が破れることに よって落下する果実の割合が増加する。