Comparison of Two Impact Detecting Devices to Measure Impact Load on Potatoes

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ABSTRACT

Mechanized production techniques cause numerous mechanical loads on perishable fruit and vegetables and, therefore, frequently mechanical damage and economical losses. Laboratory tests were conducted to measure and to compare two impact detecting devices, the artificial fruit PMS-60 measuring pressure and an acceleration measuring unit (AMU) for implantation into perishable fruit measuring acceleration. Both devices can be used to detect mechanical impact in potato processing lines. A specific test device with three conveyor belts running in circuit at four velocities of 0.2, 0.4, 0.55 and 0.65 m/s and with several free fall steps was used for the experiments. The AMU was implanted in a real potato. This potato was run together with PMS-60 and other potatoes through the conveyor belts circuit. Results showed the significant differences between impact loads recorded with PMS-60 and AMU. The AMU recorded higher impact load values at conveyor belts velocities of 0.40, 0.55 and 0.65 m/s than PMS-60, while, in the 0.20 m/s velocity, the PMS-60 recorded higher impact load than AMU. The results will be discussed.

Keywords: Impact load, Damage, Potato, Impact, Detecting device

1. INTRODUCTION

Potato tubers, carrots, bulb onions as well as apple and other fruit undergo numerous mechanical impacts during handling from harvest to packaging for retail market. It is well known that single mechanical impacts but also the sum of mechanical impacts contributes to reduction of quality and last to appreciable economical losses. Damage to tubers during harvesting and handling is one of the most important causes of lower potato quality and value, and increases the incidence of losses and diseases during storage. According to an American study (Peters, 1996), 70% of total damage is caused by harvesting, 30% during transport and storage; up to 30% of the entire product may be damaged during harvesting.

Electronic potatoes are often used to determine those zones in the harvesting and processing chain that create a certain risk level for mechanical damage to potatoes. The relationship between impact energy, registered by the electronic potato and the degree of discoloration is poorly understood. In addition many scientists use different types of instrumented bodies, which lead to hardly comparable results.

For recently developed tools, such as PTR 200, there are neither standard statistical energy level thresholds nor a frame of reference, relating sensor values to discoloration. There are numerous articles in scientific literature, which refer to the use of instrumented spheres, artificial fruits and digital or electronic potatoes to locate risk zones in fruit or potato handling chains. The most common and abundantly described types are PMS 60, a pressure measuring sphere, made at the Institute for Agricultural Engineering of Bornim, Germany (Herold et al., 1994) and Techmark's IS 100 (Michigan, USA) which measures accelerations (Zapp et al., 1989). More recently developed devices are PTR 200, manufactured by SM Engineering, Denmark in 1999; IRD 400, manufactured by Techmark, USA in 1999; and 'Smart Spud', manufactured by Sensor Wireless, Canada in 2000. These devices are equipped with tri-axial accelerometer. However, these electronic instruments currently used in agriculture are not sufficiently adapted to actual fruit properties, and therefore, the obtained data cannot be directly transferred to real fruit.

A new approach is directed to acquire data under conditions how the real produce is subject to mechanical impacts. Recently, a new approach has been proposed to overcome these disadvantages of artificial fruit. Based on a miniaturized impact detecting system, a self-contained acceleration measuring unit (AMU) has been developed in the Institute for Agricultural Engineering of Bornim, Germany (Geyer et al., 2006), that is small enough to be fitted into a real product without significant changes of the product's properties.

The objectives of this study were: to measure and to compare two impact detecting devices, the artificial fruit PMS-60 measuring impact load and acceleration measuring unit (AMU) for implantation into perishable fruit measuring impact acceleration.

2. Materials and Methods

2.1. Experimental tests under practical conditions

Laboratory tests were conducted to measure and to compare two impact detecting devices, the artificial fruit PMS-60 measuring pressure, and the acceleration measuring unit (AMU) for implantation into perishable fruit, measuring acceleration. Both devices can be used to detect mechanical impact in potato processing lines. A specific processing line simulator device was used to control the impact of the potato tubers (Figure 1).The device was consisted of three conveyor belts running in circuit. Four levels of velocity of conveyor belts at 0.2, 0.4, 0.55 and 0.65 m/s were used. The velocity of the belts was adjusted by changing the rotating number of their electromotor through an inverter set. The AMU was implanted in a real potato, which the weight of potato and AMU was equal to the weight of the PMS-60 (180 g). This potato was run together with PMS-60 and other potatoes through the conveyor belts circuit. All tests were carried out with potato tubers of the cultivar *Afra* in a range of mass between 100 and 180 g and 40 to 80 mm in diameter. According to Herold et al. (1994; 1996) and Van linden et al. (2001; 2002) at least a 10-fold repetition of the measuring run is required in order to obtain representative results. Prior to the start of the each experiment, the devices were calibrated to ensure accurate results.

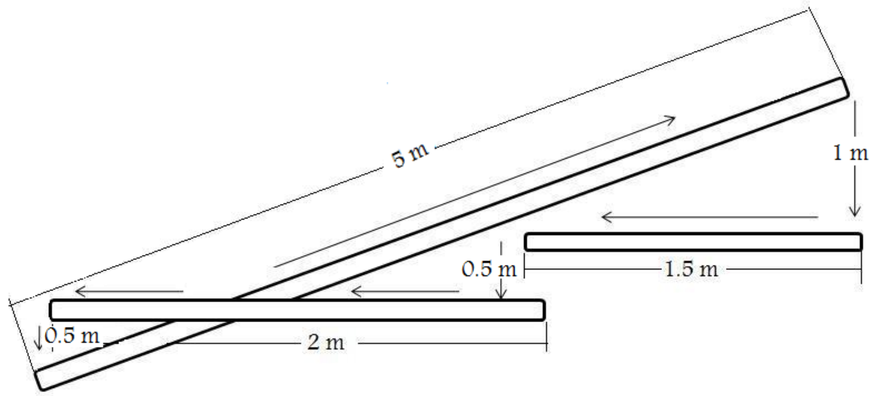

Figure 1. Schematic view of the processing line simulator test device with three conveyor belts running in circuit.

2.2. Electronic Fruit PMS-60

The electronic fruit PMS-60 (Figure 2.1) is a pressure or force measuring device constructed by the ATB (Bornim) and is capable of measuring static and dynamic loads above a pre-set threshold. The specifications of the PMS-60 are shown in the Table 1. The static and dynamic spring constants of the device approximate 20 N/mm and 80 N/mm, respectively (Geyer and Herold, 1995). The outer layer is a 4 mm thick rubber skin. An inner 42 mm diameter electronic unit is centered by means of 16 conical steel springs (Figure 2.2). The space between the inner and outer ball is filled with silicon oil. The inner ball contains all the electronic parts, including a pressure sensor, a central processing unit, an internal rechargeable battery and a communication port (Figure 2.3). The oil transmits external pressure loads to the built-in electronic pressure sensor. The sphere is connected to a power supply device that is connected to the PC to act as an interface between PC and PMS-60 for charging the batteries and for reading the data. Forces on the sphere surface cause an internal hydraulic pressure that is measured by the sensor and stored in the enclosed data logger if a pre-set threshold is exceeded. The maximum impact force (N), the impact duration (s) and the impact force integrated over the impact duration (Ns) are measured. After data collection the measured data are downloaded to a Personal Computer and analyzed. The analyzed data are indicators of mechanical damage hazard. After the transfer of measured data from the sphere to a PC, the software provides an overview on occurring impact load events by means of pressure or force-time diagram. The processed data are the available in ASCII tables for further evaluation, e.g. with MS EXCEL.

Figure 2.1 Pressure Measuring Sphere PMS-60 to measure fruit impact forces on-line.

Figure 2.2 Internal structure of the PMS-60.

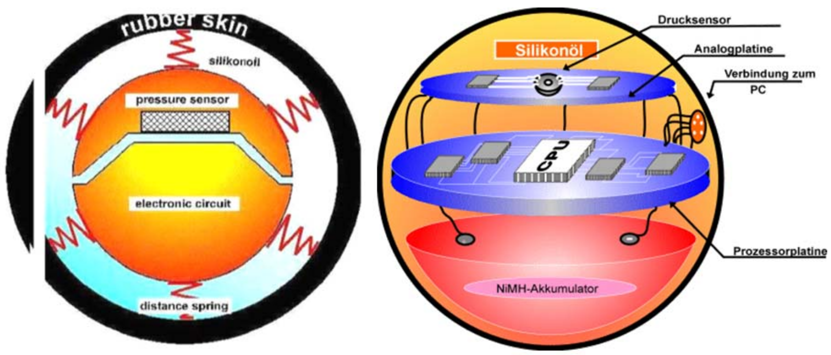

Figure 2.3 Internal electronic units of the PMS-60.

Table 1. Measuring sphere PMS-60 specifications.

Diameter	62 ± 1 mm
Weight	180 ± 2 g
Sampling rate	4 ... 10.000 samples per second. the maximum value can be sampled with higher frequency (up to 250 times of sampling rate)
A/D conversion	8 bit - resolution of internal pressure level
Measured output	Force load, Newton
Calibration	By static pressing between parallel plates
Measuring range:	0 ... 100 N statically 0 ... 400 N dynamically (t<0.1s)
Temperature range	5°C ... 40°C
Measuring accuracy	± 10% of measuring value (under conditions of calibration)
Power supply	Accumulator 5 cells NiMh 6V/60mAh
Operation time with fully recharged accumulator	typically 80 min (at 22°C)
Limits: Maximum allowed static load	100 N
Limits: Maximum allowed drop height onto concrete	1m

2.3. Acceleration measuring unit (AMU)

The parameters of the acceleration measuring unit (AMU) are shown in the Table 2. The device contained a rechargeable battery as power supply, a triaxial acceleration sensor, a data processor, and a wireless data transmitter (Figure 1). All parts were cast in epoxy resin, which ensured resistance against water and fruit acid. In the tested version, a wireless data transmission system was used consisting of a data transmitter within the AMU and a handheld data receiver connected to a PC via a USB interface (Herold et al., 2005; Geyer et al., 2006). The electronic circuitry of the AMU and data receiver was manufactured based on surface-mounted device (SMD) technology. Acceleration data were acquired in *g*'s (g = 9.81 m/s^{-2}) in a continuous way with a scanning rate of 3 kHz per axis. After processing the data of an impact event, the peak acceleration and the duration of each impact were available. Approximately every four hours, the AMU has to be recharged in a specific device (contact points for recharging shown in Figure 1.1). For use in practice, an easy method to implant the AMU into real products was developed. A potato tuber was selected and drilled with a cork borer with a diameter of 15 mm. The AMU was plugged in the longitudinal direction, into the middle of the hole, and both ends of the hole were filled with plugs tailored from the drill core. Finally, the implant was fixed with adhesive tape (Figure 1.2).

Table 2 The parameters of the acceleration measuring unit (AMU)

Geometrical and mechanical parameters		
Dimensions (Cuboid with cross section area 13 mm × 13 mm)	Length / mm	42
	Maximum width / mm	~ 17.5
	Volume /cm ^{3}	7
Weight / g	15	
Average density / g/cm ^{3}	2.1	
Measuring parameters		
Acceleration sensor:	Number of measuring channels	3
	Measuring range / G (1 G = 9.81 m/s ^{2})	200
Signal processing:	Sampling rate / 1/s	~ 3200
	Data resolution / Bit (every channel and vector sum)	8
Operation parameters:	Duration of continuous operation / h (with rechargeable accumulator)	> 5
	Operation temperature range / °C	+5 ... 35
	Radio transmission range / m	> 15
Additional features	Waterproof, resistant against fruit acids	
Data Processing:		
Platform	PC (notebook), PIII min. 800MHz, Win2000 or XP, USB interface	
Data presentation	Calibrated acceleration/time diagram (online and offline), three axes and vector sum	
Data export as ASCII-Table	Table with several columns	

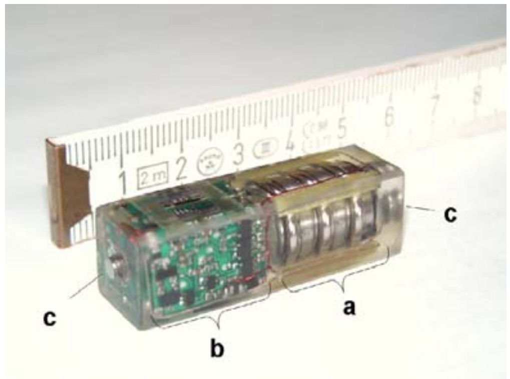

Figure 3.1. The acceleration measuring unit (AMU): a =battery, b= electronic circuitry with acceleration sensor, data processor, and data transmitter, and c = contact points for recharging.

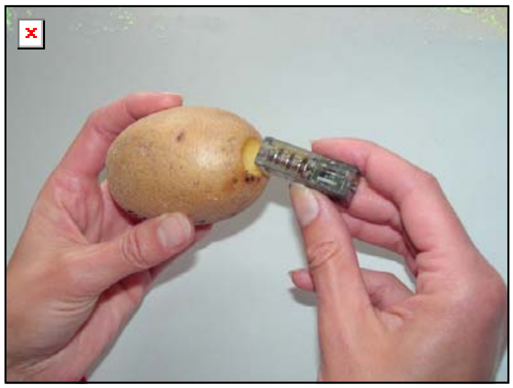

Figure 3.2. Implantation of the AMU into a potato tuber.

In order to compare impact data recorded by AMU and PMS-60, the recorded impact accelerations by the AMU were changed to impact force by using the following equations:

$F = m \times a$ (1)

Where: F= calculated impact force (N)

m= weight of potato + implanted AMU

a= acceleration recorded by AMU

2.3. Experimental design and statistical analysis

In this study, the effects of conveyor belts velocity (at: of 0.2, 0.4, 0.55 and 0.65 m/s) and impact detecting device (The electronic fruit PMS-60 and the acceleration measuring unit (AMU) were studied on the impact loads to potatoes. The factorial experiment was conducted as a randomized design with ten replications for detectin impact load to potatoes. Experimental data were analyzed using analysis of variance (ANOVA) and the means were separated applying Duncan's multiple range tests in SPSS 13 software.

3. RESULTS AND DISCUSSION

Analysis of variance of the impact load data (Table 3) indicated that the conveyor belts velocity (V) and impact detecting device (D) significantly influenced the impact load to potatoes at, 1% level. Meanwhile, the interaction effect of the V×D was significant at 5% level on the impact load. The conveyor belts velocity had the most influence and the detecting device least (Table 3).

Table 3. Results of analyses of variance (Mean Square Error) for the impact load to potatoes

Variable	df	MS	F Value
Belts velocity (V)	3	727.33	39.23 **
Detecting device (D)	1	477.50	25.70 **
V×D	3	117.31	6.32 *
Error	72	18.53	

** - significant at 1% level, * - significant at 5% level.

The mean values of the impact loads recorded by the acceleration measuring unit (AMU) and the PMS-60 at different conveyor belts velocities are presented in Table 4. From the table, it can be seen that the impact loads recorded by both devices increased with increase in conveyor belts running velocity. The lowest and highest impact load values among the combinations are 34.60 and 53.65 N that are recorded by AMU at 0.20 and 0.65 m/s belts velocities, respectively. As shown in Table 4, the AMU is recorded higher impact load values at conveyor belts velocities of 0.40, 0.55 and 0.65 m/s than PMS-60, while, in the 0.20 m/s belts velocity, the PMS-60 recorded higher impact load than AMU.

From Table 4, it can be seen that the mean values of impact load, at all conveyor belts velocities, recorded by PMS-60 is 41.07 N and this value for the AMU is 45.92 N, shows that AMU, recorded the average impact loads higher than (1.11 times) the PMS-60 sensor.

Table 4. The values of the impact loads recorded by detecting devices at different conveyor belts velocities.

Conveyor belts running velocity (m/s)	Impact load (N)	
	Detecting devoce	
	AMU	PMS-60
0.20	34.60	35.57
0.40	45.09	41.69
0.55	50.37	43.83
0.65	53.65	43.22
Mean	45.92	41.07

Table 5 shows the result of Duncan Multiple Range Tests (DMRT) on the effect of conveyor belts running velocity on the impact loads to potatoes. From the table, it can be seen that the impact loads to potatoes increased with increase in conveyor belts running velocity. From Table 5 it is seen that the effect of all belts velocity levels differed at 5% level of significance except for the belts running velocities of 0.55 and 0.65 m/s. This shows that the effect of belts velocity 0.65 m/s on the impact loads to potatoes is not significantly different from that of the 0.55 m/s belts velocity.

Table 5. Effect of conveyor belts running velocity on the impact loads to potatoes.

Conveyor belts running velocity (m/s)	Impact load (N)
0.20	35.09 c
0.40	43.39 b
0.55	47.23 a
0.65	48.44 a

Means with the same letter have no significant difference at the 5% probability level.

4. CONCLUSIONS

From the results of this study, the following conclusions can be drawn:

- Detecting device and conveyor belts running velocity were significant factors in recorded impact loads to potatoes.
- The acceleration measuring unit (AMU) was recorded the average impact loads 1.11 times higher than PMS-60.
- The impact loads to potatoes increased with increase in conveyor belts running velocity.
- Work with data the acceleration measuring unit was easier than PMS-60 device and PMS-60 was jump from conveyor belts at higher velocities.

5. ACKNOWLEDGEMENTS

This research was supported by the Horticultural Engineering Department, the Leibniz Institute of Agricultural Engineering Potsdam-Bornim (ATB).

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