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Application note

Improvement of compressive testing instrument with wide range of speed for examining agricultural materials

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ABSTRACT

Since the construction of a static and dynamic compressive testing instrument for examining biological materials, particularly fruits and tubercular roots, the need has arisen for the construction of a computer-controlled instrument that can bridge the gap between static and dynamic investigations in this field. The main utilisation possibilities of this instrument are demonstrated some measurement results with apple. The recently developed, easy-to-use instrument presented herein is suitable for serial measurements. In its present implementation, this instrument is capable of performing compressive testing with loading sticks of typical size with constant, linear slope and cosine force–time functions in single or cyclic mode. The force is generated by a PC-controlled servo system, and the deformation is measured by a laser sensor. The excitation force is 0–15 N within 1% FS accuracy in 0–300 Hz frequency range. Deformation measuring range is 10 mm with 12 μm resolution. The system contains a PC-based data logger.

1. Introduction

Perishable fruit and vegetables (e.g., carrots, potatoes, tomatoes and apples) are primarily affected by repeated loads during different processes (e.g., transporting, harvest, manipulation). In addition to its direct effect, i.e., fatigue, repeated loads play important roles in the destruction process (Fenyvesi, 2007). Previous work based on the examination of apples has shown that irrigation conditions, humidity and harvest time affect the destruction process (Garcia et al., 1995). Other work has shown that bruise susceptibility varies with apple type (Fenyvesi and Lack, 1980; Pang et al., 1994; Ragni and Berardinelli, 2001).

In the case of a static load, the characterisation of stress–bruise interactions is relatively simple. According to Mohsenin (1970) and Abbot and Lu (1996), the failure stresses of apples are approximately 0.40–0.51 MPa, varying with relative ripeness.

Extensive studies of apple bruising due to dynamic impacts have been carried out using different techniques, such as drop and pendulum tests and tests with loaded instruments to propel an apple against a counter-face (Holt and Schoorl, 1977; Ragni and Berardinelli, 2001; Bollen et al., 1999; Lewis et al., 2007).

However, little research on the response of fruit to repeated loads has been carried out. The stiffness index has been calculated using the resonant frequency of fruit (Abbot and Lu, 1996) or an acoustic method (Shmulevich et al., 2003) using non-destructive loads.

The bruising problem has been investigated using an eccentric drive oscillatory drive apparatus (Sitkei, 1978). In the case of compulsion drives, the proper loading control is not possible.

Additional investigations have addressed the bruising process using real or simulated transport in specific packaging technologies (O'Brien et al., 1965; Acician et al., 2007). Using concrete bruise measurement, software was developed to simulate the damage incurred in a given logistic scenario (Bielza et al., 2003). Studies in this direction have provided statistical functions relating damage and the mechanical effects of transport. It has been shown that the bruise level depends on the loading amplitude, frequency and number of cycles (loading time), which can be accounted for by the energy of collision (Fenyvesi and Bellus, 1998).

Loading characteristics are important for fruit damage analysis. The artificial measuring sphere was developed to determine the apparent load sustained by fruit during mechanical processes, e.g., harvest, manipulation and transport (Fenyvesi et al., 2001). According to the test results obtained using this instrument, the dynamic impacts are characteristic in terms of damage (Herold et al., 1996). For shipping, the average measured vibrational frequencies have been reported to be between 8.19 and 12.59 Hz and the range of acceleration between 0.33 g and 0.75 g (Vursavus and Özguven, 2004). If the resonance frequency of a fruit column packed into a container coincides with the excitation frequency of a given road or vehicle during transport, then the acceleration of the fruit will increase considerably due to resonance, increasing

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the severity of damage (Chesson and O'Brien, 1969). In this case, the typical frequency range is 5–50 Hz for various transportation scenarios.

Based on the literature, a computer-controlled measuring instrument that produces quick and repeated loads up to the destructive force at a frequency of at least 50 Hz should be constructed. For primarily biological damage and tension–deformation mechanical conditions, the following impacts can be distinguished. Static loads involve loading at constant force and very low speed. Dynamic loading is extremely fast, and the form of loading is neglected. Repeated loading describes an impact that changes with time and is repeating.

Based on our research, these different types of impact lead to the development of destruction or damage in different ways. Moreover, the development of damage is related to the mechanical conditions experienced by fruit, allowing for the process to be modelled.

The objective of this paper to introduce a new computer controlled compressive testing instrument, which is suitable analysing the static, dynamic and repeated effects for different biological materials.

2. Materials and methods

2.1. Hardware

2.1.1. Instrument design

Many types of biological materials and plastics are involved in the agriculture and food industry during food handling, manipulating, packing and processing. Therefore, the need has arisen for a new computer-controlled rheometer able to perform many functions rather than being a single-purpose device. In most cases, conventional testing machines can generate a static load or low-rate deformation. Oscillatory testing instruments can generate only periodic loads. Our instrument bridges the abilities of these two types of instruments. In our previous studies, a static and dynamic compressive testing instrument was elaborated to determine the viscoelastic behaviour of agricultural materials, particularly fruits and tubercular roots (Fenyvesi et al., 1989). The instrument was designed at the state-of-the-art technical level, namely, with PC data acquisition and control, but the implementation was only able to reach a preliminary stage. Advances over the last decade have created the possibility for realising a universal compressive testing instrument with a wide range of operating speeds to test the surface mechanical properties of agricultural materials.

During experiments, the elements of the rheological model for the tested area can be determined by measuring the force–deformation function or its inverse function. In many agricultural applications, the compressive force function (stimulus) is applied with an $\boldsymbol{A}$ cross-section loading pin, and the deformation (response) is recorded at the same time (Fig. 1).

Two measurement configurations are possible. First, for a known deformation–time function, usually a constant deformation speed, the reacting compressive force is measured as it is in conventional tension/compression testing machines. Second, by applying a known compressive load, the deformation can be measured and recorded. In the case of low-force and high-speed servo applications, the second configuration is preferable. Commonly used screw-bolt testing machines can only function at low deformation rates, and the $\boldsymbol{F(t)}$ reaction force as a response function can be measured. High deformation rates can only be realised with some difficulty.

For many agricultural materials, e.g., fruits and tubercular roots, only an approximately 10 N compressive force is needed when employing commonly used ∅ 4 mm, 5 mm and 6 mm loading pins in loading pin tests. The surface deformation is below 10 mm, and the loading and measuring system bandwidths must range from 0 Hz to at least 100 Hz. With 0 Hz as the lower cut-off frequency, the measuring system can operate in static or slow-rate mode, whereas an upper cut-off frequency of 100 Hz allows this range of vibrations to be tested with the same instrument. The electromechanical loading system is a computer-controlled feedback servo system that is capable of generating a pre-determined force–time function in the range of 0 to approximately 300 Hz. This component consists of a drive mechanism, a force sensor and the moving part of the deformation or displacement sensor. Because of the wide frequency range, the mass of the loading or "moving part" of the instrument must be very low.

2.1.2. Sensors

A special low-mass strain gage (SG) force sensor was designed for use in the instrument. The measuring body was made from high-strength aluminium alloy. To the surface of the bending beam portion of the measuring body, 120 Ω Kyowa KFG-2-120-C1-23 self-compensated strain gages with a 2-mm active measuring grid length were applied in a full bridge configuration (Fig. 2). Because of the self-compensated gages and the full bridge configuration, the temperature dependence of the sensor is very low. Every bridge arm consists of two SGs; therefore, the suppression of the parasitic load effect is very good, and the sensitive direction of the force sensor is along the symmetry axis. Due to the serial connection of the SGs, the bridge resistance is 240 Ω.

The force transducer operates together with the measuring amplifier. A HBM RM4220 measuring amplifier was chosen because of its wide and adjustable bandwidth and 10 V analogue output voltage range.

The other sensor in the instrument is the deformation sensor. Its size and form must fit the measuring head. Our previous experiments showed that approximately 0.01 mm resolution over a range of 10 mm is acceptable. The bandwidth must be as high as possible and at least 1 kHz. The contactless measuring principle is self-evident. The OMRON ZX series ZX-LT010 laser through-beam

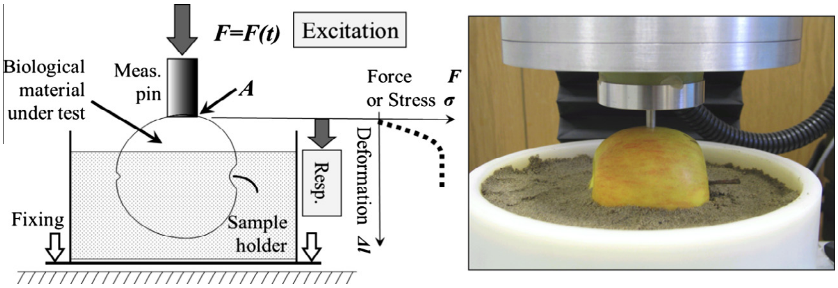

Fig. 1. Scheme of the measuring set-up and a real measuring situation.