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Numerical Simulation and Experimental Validation of a Vibrating Screen for the Sieving of Chamomile (Matricaria chamomilla L.)

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Chamomile (*Matricaria chamomilla* L.) dried flowers contain a large number of interesting biologically active compounds which make it an important medicinal herb. In order to preserve the commodity quality and the biologically active compounds of chamomile, the correct management of the chamomile processing process coming from the field is fundamental. An important phase of the chamomile process is the final sieving of the dried chamomile in which the intact flower heads are separated from the other parts of the flower. In this study a simulation of a vibrating screen machine was carried out in order to find the best kinematical parameters that allow to improve efficiency during the sieving process of chamomile. The study of the movement kinematics provides the acceleration of the vibrating screen depending on its geometric and mechanical characteristics. The frequencies and amplitudes of the vibrations transmitted to the screen were estimated in the main directions, and the optimal parameters were evaluated to guarantee high sieving efficiency and reliable productivity of the machine. To validate the modelling experimental tests were performed by installing three tri-axial accelerometers on the mobile frame of the machine, in order to obtain an accurate measurement on the three reference axes. The comparison of the measured values with the simulated ones demonstrated the suitability of the numerical simulation and its ability to estimate the process performance. Finally, experimental tests demonstrated that by using the optimal sieving frequency a significant reduction of waste was possible, with a consequently increase in the fraction of dried whole and intact flower.

1. Introduction

Chamomile (*Matricaria chamomilla* L.) is one of the most ancient medicinal herbs native to southern and eastern Europe (Ling et al. 2020). The flowers of M. chamomilla contain large group of therapeutically interesting and active compound classes (Singh et al. 2011) with anti-inflammatory properties and bacteriostasis associated for disturbance of the stomach, diarrhea, nausea (Ghasemi et al., 2020; Bagheri et al., 2020) and colic in adults and infants (Crotteau C. A. et al., 2006). It is used mainly as a tisane by infusing whole or shredded flowers of dried chamomile in hot water. To make it more practical to use, the dried chamomile can be placed in filter paper bags.
The chamomile processing is schematically represented in Figure 1. After the mechanical harvesting the raw product is transferred to the production plant. Here it is discharged into a hopper and distributed in a conveyor belt buffer to be cooled and remove a first fraction of moisture. Subsequently the product undergoes a first sieving to select the flowers with a stem up to about 7 cm. A sorting machine divides the flowers with stems up to 3 cm from the remaining part, which is sent to a cutting-stem section to standardize the product. However, in the post-harvest treatment of chamomile a crucial phase is drying. The drying is performed in static or dynamic dryers, by inserting the product inside and hitting it with hot air with a humidity lower than the humidity of the product to be dried. Drying is an important process for preserving plant material, as it inhibits

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enzymatic degradation and limits microbial growth. In order to investigate the effect of drying on the final quality of chamomile, several studies were carried out (Fennel et al., 2004; Borsato et al., 2005; Harbourne et al., 2009). Only at the end of drying, the product undergoes a final sieving to remove the last residues of weeds and convey the final product in storage box.

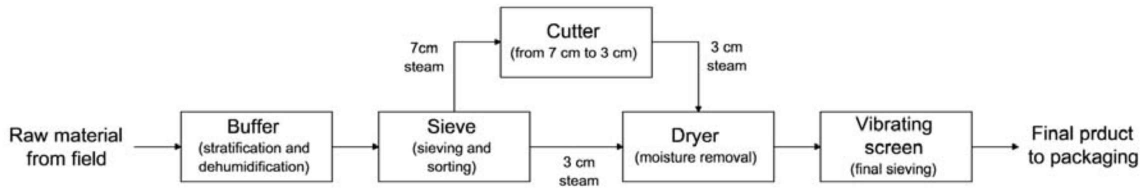


Figure 1: Chamomile processing

In the chamomile market the highest commercial category is represented by dried whole and intact flower. To produce this commercial category a delicate and careful final sieving is carried out to separate the whole flowers from the others part of the dried material. However, despite the importance of this production stage there have been no data published on the effect of sieving parameters on the sieving performance in order to obtain useful results for the design of the sieve and their correct adjustment of the functional parameters. These aspects also greatly influence the energy performance of the process, which is to date a major concern (Perone et al., 2017).

Instead of directly realize and testing physical prototypes of the mechanism, it is desirable to evaluate the mechanism functioning by simulating a new prototype. Many studies focused on kinematic and dynamic analyses of vibrating screen and sieve. He and Liu (2009) studied the ideal motion characteristics of a new vibrating screen with variable elliptical trace by computer simulation, and found that that the motion simulation to design the vibrating screen is able to effectively improve screening efficiency. Shen et al. (2009) simulated a three-dimension solid model motion of a new concept of vibration sieve based on parallel kinematic mechanism. They concluded that the simulation provided essential information for optimizing the design of the prototype, which is manufactured at last. Liu et al. (2014) conducted static and modal analysis and claimed that the simulation can effectively reduce the number of test machines, shorten product development cycles and reduce development costs.

In this study has been simulated the kinematic analysis of a vibrating screen to evaluate its behavior in sieving and conveying the chamomile. The motion study has hallowed to predict the main acceleration components of the sieve. Finally, the results have been validated through experimental measurements of the vibration.

2. Materials and methods

2.1 3D modelling and Motion study

To evaluate the efficiency of the vibrating screen a kinematic simulation analysis was performed. In particular, after the modelling of the assembly, it was used SolidWorks Motion, which is able to simulate moving system and returns outputs to better understand its operation. Motion is able to analyse models that involve moving parts. In detail, the software allows to size the model and determine how contacting parts behave, without performing tests of physical prototypes. These information are essential to obtain insight on how the mechanism works and why it operates in certain ways.

Figure 2 shows the 3D modelling of the vibrating screen used for the motion study. It consists of an assembly of the following parts:

- Sieve – which is the upper mass to sieve and conveying the product;
- Motion Frame – to convert the rotational motion of the motor into a reciprocating motion, and to balance the sieve inertial forces;
- Fixed Frame – through its pins it acts as a hinge for the rocker arms;
- 4 Rocker arms – with a tilt angle of 20°, to transfer the motion from the motion frame to the sieve, and to add stiffness to the system.
- A virtual oscillating motor generated the motion of the assembly (red arrow in Figure 1). The motor was set to perform the analysis at frequencies of 5 Hz and 3.3 Hz. The displacement was calculated according to the eccentric of the motor and an empirical correction is made, due to the elasticity of the transmission. In fact, the motion analysis was solved for rigid body kinematic problem, using a time-based approach. These assumptions were made to simplify the model, which required a lesser

number of components and therefore fewer degrees of freedom, without modifying the actual operation of the vibrating screen.

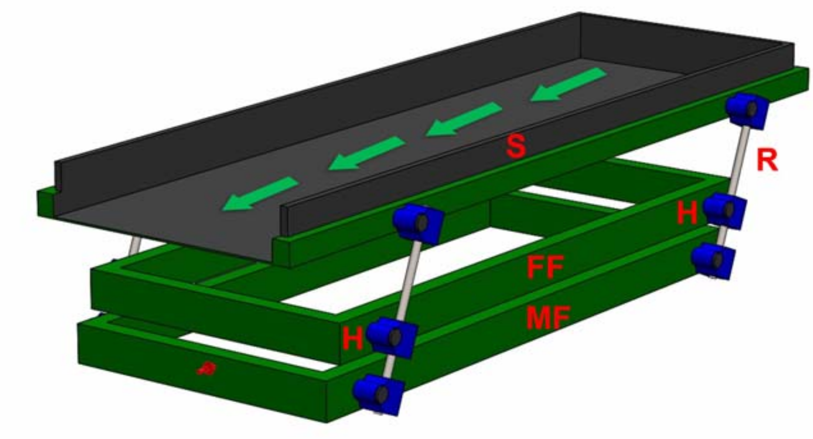


Figure 2: Vibrating screen 3D model. H – Hinge; MF – Motion Frame; FF – Fixed Frame; R – Rocker; S – Sieve; Red arrow – Virtual oscillating motor; Green arrows – conveying direction.

2.2 Experimental Vibrating screen

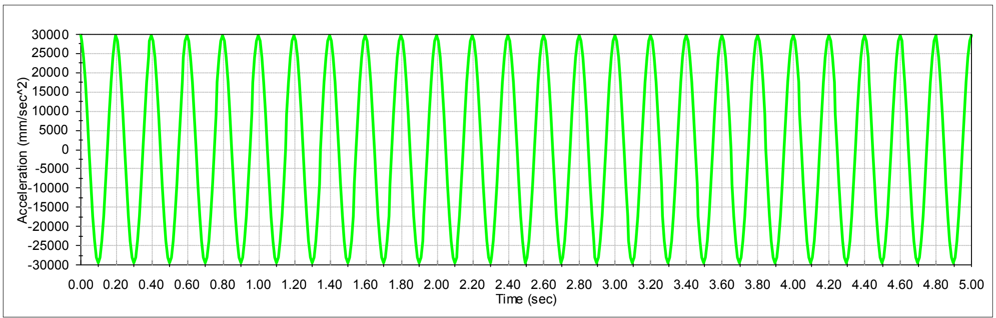
The vibrating screen (Figure 3) consists of two masses directly connected by means of double rocker arms hinged on a fixed frame. The upper mass is the sieve, while the lower mass is the motion frame. The weight of the two masses are almost equal and thus the resulting inertia forces of the sieve are fully compensated. The motion frame is moved by a motor with eccentric and a crank connecting rod system, and the motor is driven by an inverter. In this way, when the lower mass is pushed by the connecting rod, the rocker arms are forced to rotate around the hinges on the fixed frame moving the sieve in the opposite direction. The reverse situation occurs during the return stroke of the connecting rod. The resulting motion is a rotation of about ± 6° around the initial position. As a result, the sieve theoretically undergoes a displacement both in the longitudinal and vertical direction. Actually, due to the elasticity of the connection between the motion frame and the rocker arms, there is also a transversal component.

Figure 3: Vibrating screen - Experimental apparatus.

The vibration measurement system was composed of three tri-axial accelerometers (PCB 356A16, Depew, NY, US); a NI USB-6255 A/D card connected to a notebook; a NI SCXI 1531 signal conditioning module equipped with a band-pass filter with cut-off frequencies of 0.2 Hz and 500 Hz; and custom software written using LabView (National Instruments, Austin, TX) for visualising, recording and processing data coming from the accelerometers. The sampling frequency was set to 1000 Hz. Before any other numerical processing, a digital filter was used to limit the bandwidth up to 150 Hz (3 dB cut-off frequency). In particular, a moving average filter was used. The accelerometers were fixed to the structure of the sieve through magnets. The accelerometers sent an analog signal to a conditioning block that analysed the input and returned the three components for each accelerometer. Tests was carried at 5 Hz and 3.3 Hz, which are the same of the simulation, by variating the frequency of the motor through the inverter.

3. Results and discussions

The kinematic simulations allowed to evaluate the vibration of the sieve through the calculation of the acceleration components. Figure 4a and b show the linear acceleration in longitudinal and vertical direction respectively, when the frequency was 5 Hz. The transversal component is neglected since the simulation is performed on a rigid body. It can be seen that the action of the vibrating screen in the longitudinal direction reached a very strong value of about 30 m/s^2, and also the vertical component had an appreciable value of about 20 m/s^2. This is definitely a desirable effect, since the main action of the machine is that of sieving and moving the chamomile forward. However, the vibration action is too high and could lead to unwanted product loss.



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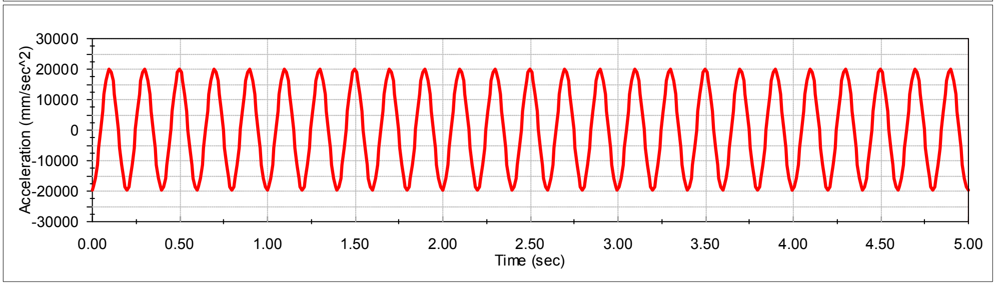
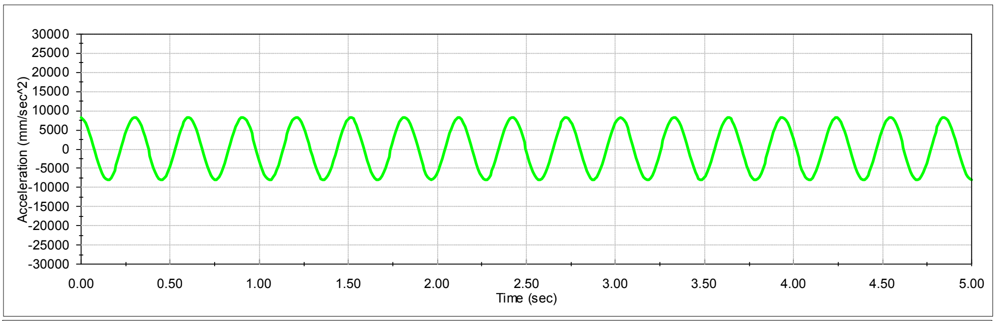


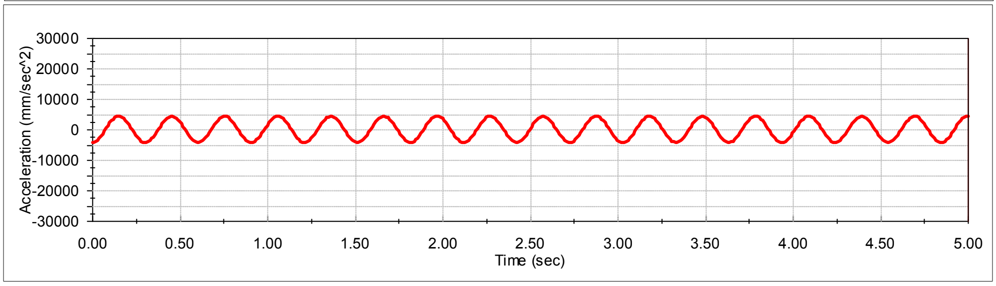
b)

Figure 4: Linear acceleration components at 5 Hz – a) longitudinal component; b) vertical component.

Also in the case of the oscillating motor at 3.3 Hz the behaviour is substantially the same (Figure 5a, b). The action of sieving and conveying is well managed. The longitudinal linear acceleration was about 7.5 m/s^2, while the vertical component was around 5 m/s^2. This means that the action of the four rocker arms allowed to balance the sieve and enhance the performance of the machine. In this way, it is possible to avoid unnecessary vibrations in the transverse direction, which could lead to a greater loss of thin vegetable fraction. The simulation results were endorsed by experimental tests (Figure 6a, b), whose difference highlights an error of less than 10 %. Figure 5a show the acceleration components when the frequency was 5 Hz. The y direction coincides with the longitudinal direction, the x axis with the vertical direction, and the z axis with the transversal direction. The longitudinal acceleration is the major component, while the vertical acceleration is reduced by one third and was still considerable. The transversal component, despite the strong power supplied by the motor, is only a third of the longitudinal component and a half of the vertical one. In the case of motor speed at 3.3 Hz, the ratio between the longitudinal and vertical direction is almost equal to the previous case and equal to about 1.5. However, in this configuration the transversal component is completely negligible, confirming the results obtained in the kinematic simulation. As said above, this is an appropriate working condition, since the chamomile experiences a good sieve during its conveying towards the output of the machine. Hence, the experimental results confirmed that using the optimal screening frequency (3.3 Hz) a significant reduction of the sieving waste is possible.

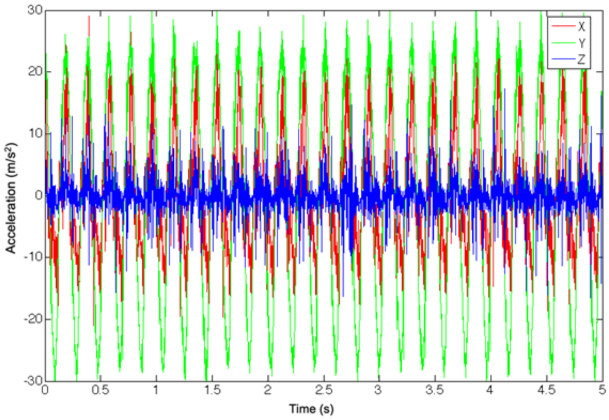


a)

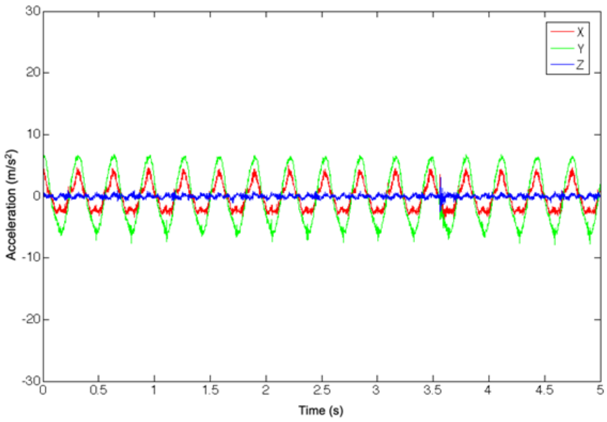


b)

Figure 5: Linear acceleration components at 3.3 Hz – a) longitudinal component; b) vertical component.



a)



b)

Figure 6: Experimental measurements of acceleration components – a) 5 Hz; b) 3.3 Hz.

4. Conclusions

The accurate processing of Chamomile (*Matricaria chamomilla* L.) is essential to preserve its quality and biologically active compounds. The proper control of the final sieving of the dry product is strictly connected to the quality of the final product, since it allows to correctly separate the fraction of dried whole and intact flower. In order to optimize the setup of the machine, a kinematic simulation of the vibrating screen was performed. The main results highlight that the use of four rocker arms between sieve and motion frame assimilate the elastic system to a rigid body, also when the vibrating screen was driven at a frequency of 5 Hz, which produced a strong acceleration. In fact, the transversal component of the acceleration was negligible respect to the longitudinal and vertical components. However, this condition is too extreme and could lead to an undesirable loss of the final product. The best results were observed when the oscillating motor was set at 3.3 Hz. In this case the ratio between the longitudinal and vertical acceleration is 1.5 (as in the previous case), but the transversal component is almost nil. These results were confirmed by experimental tests performed by means of three accelerometers installed on the sieve frame and by experimental screening tests that demonstrated a significant reduction in waste when the optimum frequency was used. This emphasizes the reliability of the kinematic simulation through the motion study in predicting the performance of the vibrating screen.

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