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(54) Title: SHAKER FOR FRUIT HARVESTING

(57) Abstract: Shaker for fruit harvesting the shaking patterns of which are changeable while the shaker is continuously operating is disclosed. The vibrating mechanism of the shaker comprises at least three eccentric rotators, the rotational speed of each of which is respectively controlled. Furthermore the instantaneous rotational angle of each rotator is continuously monitored. A method for suitably selecting the rotational speeds of each rotator and the relative rotational phases associated with selected pairs of rotators, such that a desired shaking pattern is accomplished, is further disclosed. Measuring the instantaneous rotational angle of each rotator provides for controlling the levels of relative rotational phase associated with selected pairs of rotators.

SHAKER FOR FRUIT HARVESTING

FIELD OF THE INVENTION

The present invention relates in general to shakers for harvesting fruits. In particular the present invention relates to a shaker for harvesting fruits the vibrational modes of which are controllable and can be changed while the shaker is operating.

BACKGROUND OF THE INVENTION

Shakers accommodated to vibrate a tree for harvesting fruits are common in the marketplace. Often the shakers are adapted and arranged to be mounted onto common tractors. Typically, two or more clamping members of a shaker are adapted and arranged to grip the trunk or limb of a targeted tree. The gripped tree is further shaked and vibrated by means of an integral vibrating mechanism of the shaker.

Exemplary vibrating mechanism of a shaker for harvesting fruits is disclosed in US patent 3771768. The disclosed mechanism has three eccentric masses such arranged that they rotate at three different parallel planes. All the three masses have the same mass eccentricity. The outer eccentric masses are equal in weight and are synchronously rotated at the same rotational speed in the same direction. The inner mass its weight equals the sum of the weights of the other two masses rotates at the same speed but in the opposite direction. In US patent 4128986 a shaker the vibrating mechanism of which provides for modifying the vibrational modes induced and applied onto an engaged tree is disclosed. The vibrating mechanism of the disclosed shaker has two eccentric rotatable masses the magnitude and/or direction of the rotational speed of each of them is changeable by the user. Such changes are accomplished by changing the rotational speed of the respective hydraulic motor driving a mass and/or by convolving one of the belts transmitting the rotational motion to a respective mass, or by changing the transmission ratio by selecting among different pulleys to be engaged with a respective belt. Another shaker the vibrating mechanism of which has two eccentric rotatable masses is disclosed in US patent 5473875. The eccentric masses of this shaker rotate at the same rotational speed but in opposite directions. The shaker further has a controller providing for coordinating the rotation of the eccentric members such that their asymmetric portions align at two diametrically opposed points but are retained out of phase during the reminder of a rotation cycle. Therefore the trunk of a tree engaged with the shaker is vibrated along a single axis specified by the selected alignment of the rotation. The controller further randomly changes the direction of the axis of vibration and monitors the resulting amplitudes of vibration to select a direction in which the amplitude is the largest. An improved version of a vibrating mechanism having two rotatable eccentric masses is disclosed in US patent 6672044. The disclosed mechanism provide for changing the weight of the eccentric mass as well as for changing the location of the center of mass of each rotator.

However except for changing the rotational speed of a motor driving a rotator of any of the above described vibrating mechanisms, which can be accomplished while the shaker is in operation, all other means for modifying the vibrational modes can be effected when the shaker is not operating. Typically such changes involve dismantling replacement, and/or adjustment, of specific members of the mechanism, reassembly and tuning of the assembled mechanism. Obviously such activities are not suitable for successively shaking a number of trees, at least some of which are to be individually addressed. A different approach by which the eccentricity of the rotating masses can be dynamically changed is disclosed by Affeldt et. al. in a paper published in J. Agric. Engineering Res. (1989) 44, 53-66. These researchers have tested the efficacy of shaking a number of different kinds of trees by a number of different shakers among them is one which is capable for dynamically changing the eccentricity of a rotating mass. Obviously such capability provides for changing the vibrational mode of the shaker while is operating in addition to varying respective rotational speed levels. It is a common knowledge that different vibrational modes when applied unto a tree engaged by a shaker may differently affect the efficiency of the harvesting. Additionally, too vigorous vibrations may cause harm and risk the health of a shaked tree.

Therefore any shaker for harvesting fruits that provides for shaking a tree in various vibrational modes; modes that can be selected from a given variety of different vibrational modes; modes that can be modified and controlled by the user while the shaker is operating, such that the efficiency of harvesting is promoted and yet risks considering hazards that might damage the bark are substantially reduced, is beneficial.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an isometric view of a shaker for harvesting fruits (SHF) according to an embodiment of the present invention;

Fig. 2 is a schematic presentation of a segment of a gripping unit of a SHF in accordance with a preferred embodiment of the present invention enclosing a trunk of a tree;

Fig. 3 is a schematic presentation of a segment of a vibrating mechanism of a SHF according to a preferred embodiment of the present invention;

Fig. 4 is a schematic presentation of a segment of a vibrating mechanism of a SHF according to another preferred embodiment of the present invention;

Fig. 5 is a sectional view of the rotators respectively shown in Fig. 2 and Fig. 3;

Figs 6 – 17 are polar graphs respectively presenting various vibrational modes that can be generated by means of a SHF of the present invention;

DETAILED DESCRIPTION OF THE PRESENT INVENTION

In accordance with the present invention a shaker for harvesting fruits (SHF) the vibrational modes of which are controllable and changeable is provided. A mounting frame of the SHF of the present invention is structured and arranged such that it can be connected to a vehicle such as any common tractor. The vibrating mechanism of a SHF of the invention can be energized by energizing means that are normally available at common tractors. A SHF of the invention provides for shaking a trunk or a limb of a tree in any of a plurality of vibrational modes often called "shaking patterns". The vibrating mechanism of a SHF of the invention includes at least three rotatable eccentric masses the instantaneous rotational angle of each of which is measured. Such vibrating mechanism provides for changing from one vibrational mode to another, which is different from the first one, either automatically or by a user demand while the vibrational mechanism is continuously operating. Exemplary is continuously shaking a targeted tree by a number of alternately changing different vibrational modes along a time interval the length of which is of a few dozens of seconds. Shaking at a predefined vibrational mode is automatically controlled by means of an integral controller. A SHF of the invention is characterized by its inherent capability to control the respective rotational speeds of each of its integral rotators as well as the respective rotational phases between selected pairs of rotators.

Reference is now made to **Fig. 1** in which an isometric view of SHF **10** which is in accordance with an embodiment of the present invention is shown. Connecting brackets **12** disposed at the proximal end of mounting frame **14** provide for attaching SHF **10** to a tractor. Attaching is accomplished as known, by means of three points hitch such as any of common agricultural equipment attachable to a tractor. Lowering, elevating and/or rotating the SHF relative to the tractor is accomplished by means of a lowering/elevating and rotating mechanisms integral to, or mounted on, the tractor as known. Mounting frame **14** is downwardly inclined (distally, off the tractor and towards the gripping unit **16**). Gripping unit **16** is further proximally inclined off mounting frame **14**. Both inclination angles provide the operator for clearly visualizing the trunk or a limb of a targeted tree and both of clamping jaws **18, 19,** while straightly approaching the tree. Clamping jaw **18**, which is disposed proximal to mounting frame **14**, is firmly secured to mounting frame **14**, whereas clamping jaw **19** is pivotally attached to clamping jaw **18**. Moving the distal jaw for gripping or releasing a tree is accomplished by means of hydraulic piston **20**. Pads **22** that are typically made of a somewhat compressible and mainly friction withstanding material, such as rubber typically utilized for manufacturing tires for heavy duty, provide for securing the surface of the trunk as known. A touch sensor, not shown, is such disposed that it interleaves between clamping jaw **18** and its associated pad. This sensor provides for alerting the operator that the pad associated with clamping jaw **18** is pressed against a surface of the tree. Typically a pressure gage implements such sensor. Such pressure gage further provides for measuring the level of instantaneous amplitude of vibrations, thereby providing for characterizing the vibrational mode that is the currently operative. In a case in which the measured amplitudes range is either lower than or greater than respective predefined vibrational thresholds the operator is automatically alerted by the SHF accordingly. Housing **24** encloses the vibrating mechanism, not shown.

Reference is now made to **Fig. 2** in which a segment of gripping unit **40** of a SHF according to a preferred embodiment of the present invention is schematically shown. Clamping jaws **42** and **44** are the respective proximal and distal jaws of gripping unit **40**. Sensor **46** is housed within a niche disposed at the distal wall of clamping jaw **42**, which is the wall facing trunk **48** of a targeted tree. Sensor **46** is any of touch sensors, such as a pressure gauge or a micro-switch that closes an electrical circuit when is being pressed, or proximity sensors, such as an ultrasonic sensor providing for measuring a distance to a reflecting surface. All such sensors are referred hereinafter as proximity sensors. Each clamping jaw of gripping unit **40** is provided with a pair of inflatable pads **50** symmetrically disposed relative to a line normal to clamping jaw **42** and crossing it at a close proximity to the geometrical center of sensor **46**. Activating the proximity sensor brings about tightly securing gripping unit **40** to trunk **48**, which is accomplished by automatically diminishing the spacing between clamping jaws **42** and **44** concomitantly with inflating the pads. For releasing the trunk first the pressurizing fluid is evacuated off the pads and then the spacing between the clamping jaws is increased back to the stage in which the jaws are fully opened. The walls of the inflatable pads are somewhat expandable and mainly collapsible when are exposed to a relatively high stresses. They are typically made of friction withstanding materials such as hard rubber that is typically utilized for manufacturing tires for heavy duty. All the four pads have a respective electrically operated inlet/outlet valve providing for pressurizing a fluid such as air, or hydraulic fluid, into the lumen of a pad for gripping, and evacuating the pressurizing fluid for releasing, a trunk of a targeted tree. Embodiment variants in which a trunk of a tree is gripped by more than two clamping jaws are in accordance with the present invention.

The controller of this SHF, not shown, is typically mounted at a pre-selected site located on the tractor such that its screen and operating keys are conveniently visualized and/or accessed by the user while is sitting at the driver's seat. Electrical cabling, not shown, that passes through the lumen of the mounting frame provides for transferring signals and statuses originated by sensors, such as shaft encoders and proximity sensor, and/or devices, such as electrically controlled valves and/or actuators, embedded in the gripping unit and transmitted to the controller and/or commands and data transmitted by the controller to respective embedded devices and sensors.

Vibrating Mechanism

The vibrating mechanism according to the present invention includes at least three rotators the instantaneous levels of their rotational speeds and angles are controllable. Such vibrating mechanism provides for dynamically changing an operative vibrational mode while the SHF is continuously operating. An eccentric mass of a given weight and eccentricity implements a rotator of a vibrating mechanism according to the present invention. The center of mass of each rotator is laterally displaced from its respective axis of rotation by a pre-defined distance. Each rotator rotates at a given rotational speed, the magnitude and direction of which is controlled at given respective levels along specified time intervals. The respective rotational angles of any rotator of at least one pair of rotators are such controlled that both rotational angles associated with this pair of rotators are synchronized. Any number of such rotators that is equal or greater than three is in accordance with the present invention. Preferable are vibrating mechanisms having three coaxial rotators as the variety of the vibrational modes provided by such mechanisms normally suffices to efficiently harvest a considerable amount of different types of fruits and yet providing for dynamically varying a vibrational mode while the vibrating mechanism is operating.

Reference is now made to **Figs 3 – 5**. In **Fig. 3** a segment of vibrating mechanism **60** of a SHF according to a preferred embodiment of the present invention is schematically shown. Three rotators **62** each of which is rotatably attached to common axis **64** by means of respective bearing are independently driven, such as by timing belts. Each of the belts is independently driven by a respective pulley, such as pulley **66** that drives belt **68**. Pulley **66** is firmly connected to rotating axis **70** that is further connected directly or through a transmission gear as known, to the axis of a respective motor, not shown. Any kind of common motors their rotational speed is controllable can be employed for driving the rotators of a vibrating mechanism. Preferable are hydraulic motors that can be energized by an integral hydraulic pump and tanks of the vehicle carrying the SHF or by an additional pump that is powered by an integral power takeoff of the vehicle employed. Any sensor providing for measuring an instantaneous rotational angle of rotating axes and/or the rotators of the vibrating mechanism are applicable according to the present invention.

Shaft encoders **72** which are among such sensors, each of which is connected to a respective rotating axis, provide for independently measuring the instantaneous rotational angle of any rotator among rotators **62**.

In **Fig. 4** a segment of rotating mechanism **80** of a SHF according to another preferred embodiment of the present invention is schematically shown. Similarly to the vibrating mechanism described with reference to **Fig. 3** hereinabove all the rotators of rotator member **82** are driven by timing belts.The intermediate rotator is independently driven by one motor, whereas both externally disposed rotators **83** are driven by another motor, which is different from the first one, not shown. Therefore both rotators **83** rotate at the same rotational speed and the same direction whereas the intermediate rotator independently rotates at any desired direction and speed. Clutch (exemplary is an active clutch such as a rotary actuator; however a common passive clutch is applicable as well) **84** couples between rotating axes **86** and **88**. Clutch **84** provides for momentarily changing the rotational angles between exes **86** and **88** by a predefined level in a controlled manner. Shaft encoders **92** and **94** provide for measuring the instantaneous levels of rotational angles of axes **86** and **88** respectively. Shaft encoder **96** provides for measuring instantaneous rotational angles of rotating axis **98**. In **Fig. 5** a sectional view of rotators member **100** that is used in both above described vibrating mechanisms is shown. Bearings such as bearing **104** provide for rotatably attaching a rotator to common axis **106**. The weight of rotator **102** equals the sum of weights of both rotators **103**; both rotators **103** have the same weight and the same mass eccentricity. Embodiments in which the weight and/or the eccentricity of both outer rotators are not the same are in accordance with the present invention.

The azimuth angle associated with the center of mass of any rotator of rotators member **100** measured in a coordinate system the x-y plane of which is parallel to the planes (all of which are mutually parallel) in which each rotator respectively rotates, uniquely defines the rotational angle of the rotator considered. Therefore in cases in which the belts that drive the rotators are suitably stretched, any of the shaft encoders **92 – 96** provides for independently measuring the instantaneous levels of the rotational angle of any of the rotators respectively.

The vibrating mechanism of a shaker of the invention may have two or more sets of rotators some of which are respectively installed at different clamping jaws of the gripping unit. Such vibrating mechanisms are referred hereinafter as distributed vibrating mechanism.

Relative rotational phases and vibrational modes

The difference between rotational angles respectively associated with any pair of rotators is defined as the relative rotational phase associated with these rotators. The magnitude of the instantaneous level of the relative rotational phase associated with a pair of rotators rotating at respectively given rotational speeds, either cyclically oscillates, or is fixed in time. Let us designate this magnitude by $\phi(t)$. In a case in which each rotator, respectively designated by the index "i", its value is given by either i=k, or i=l, ($k \neq l$) rotates at a respective rotational speed the magnitude of which is retained constant and is designated by ω_i, (ω_i=constant), and both rotators rotate at the same direction, the level of the instantaneous relative rotational phase $\phi(t)$ cyclically changes in time at a rate its magnitude is given by $\Omega=|\omega_K - \omega_l|$, such that $\phi(t)=\Omega t+ \phi_0=|\omega_K - \omega_l|t+ \phi_0$, where $|\omega_K - \omega_l|$ designates the absolute value of the difference of the respective rotational speeds, and ϕ_0 is the respective level of the relative rotational phase measured at a given time its value is selected to serve as the origin of the time scale. For example, in a case in which both rotators rotate at the same rotational speed in the same direction, the instantaneous level of the relative rotational phase does not change in time, namely $\phi(t)=\phi_0$=constant. If one of these exemplary rotators rotates in the opposite direction compared to the other rotator, then $\phi(t)$ cyclically oscillates at a rate given by $\Omega=|\omega_k|+|\omega_l| =2\omega$, where ω is the magnitude of the rotational speed of each rotator. The rotational speed is basically a vector, therefore the rate in which the relative rotational phase varies in time is given up to a sign be the vector equation $\vec{\Omega}(t)=(\vec{\omega}_k(t)-\vec{\omega}_l(t))t$, where k, l are the indexes designating the rotators considered. Therefore up to a sign (which is dependent on the order by which the respective rotational velocities are subtracted one from the other) the relative rotational phase is uniquely defined by its initial level ϕ_0 and the rate Ω by which it oscillates in time. Cases in which the rotational angles of each rotator is respectively measured at different coordinate systems the origins of which are displaced by a given vector (having a predefined magnitude and direction) are in accordance with the present invention. In such cases (in which the axes of rotations of both rotators differ one from the other) the relative rotational phase is similarly defined and its time profile is similarly derived.

In a case in which a rotational bearing provides for engaging a rotator with its axis the initial relative rotational phase between this rotator and any other rotator is arbitrary. Similarly the relative rotational phase of any pair of rotating rotators can be of an arbitrary level. However by repeatedly accelerating one rotator up or alternatively slowing down the other rotator and let both of them rotate at the modified rotational speeds for a while and further bringing them back to the same initial velocities one can change the level of the relative rotational phase associated with this pair of rotators. Hence by means of a closed loop control mechanism implemented, such as by the operating software of the integral controller, the magnitudes of the respective rotational speeds as well as the relative rotational phases can be adjusted to respective desired levels considering a selected pair of rotators of a vibrating mechanism according to the present invention.

A vibrational mode is characterized according to the present invention by the respective magnitudes and directions of the rotational speeds of all the rotators of a vibrating mechanism, the relative rotational phases associated with the set of selected pairs of rotators of the vibrating mechanism considered, and the time along which all these values are retained at the same respective levels. The minute in which any of these parameters changes starts a new vibrational mode having the same parameters as of the preceding mode except for the only parameter that its level has been just changed.

Operating a SHF of the invention

The operator first drives the vehicle carrying an SHF of the invention to bring it to a stand in which both clamping jaws are placed at the opposing sides of a trunk or limb of a targeted tree. Then the gripping unit, which is initially being at a stage in which the clamping jaws of the gripping unit are fully opened, is tightly secured to the tree. Such securing can be accomplished either automatically, by being activated by the integral proximity sensor; or semi-automatically, by a manual activation accomplished by the operator who presses a respective operating key of the integral controller, or manually by the operator who manipulates the valve of the hydraulic piston that moves the respective clamping jaws. At this stage the operator either selects a pre-stored vibrational mode or generates a tailor made vibrational mode, which can be stored in a database to be further regarded as a mode defined by the user. The vibrating mechanism is automatically activated along a pre-stored shaking time interval, or along time interval as is currently set by the operator. The SHF starts shaking the tree by activating the vibrating mechanism such that each rotator rotates at a given rotational speed in accordance with the respective vibrational mode while controlling and synchronizing the rotational speeds of the respective rotators and/or their relative rotational phases. The controller is operative in automatically adjusting the respective rotational speeds and/or the relative phases involved. The controller intermittently changes the levels of respective rotational speeds and/or phases such that the vibrating mechanism follows the desired vibrational mode along the respective time interval as is stored in the database or set by the operator. The operator is optionally presented with both profiles of the desired as well as with the currently measured profile, both of which are presented across the screen of the controller. Optionally the operator is similarly presented with the currently measured amplitudes in comparison with the desired levels and the respective vibrational thresholds. In a case in which the currently measured profiles deviates from the respective desired profiles and the deviation ranges beyond a predefined limit the operator is immediately alerted and the level of the deviation is displayed to her or him across the screen of the controller. Similarly the operator is alerted in cases in which the measured amplitudes cross their predefined thresholds. In such cases the operator may switch to another vibrational mode stored in the database, or manually change selected rotational velocities and/or relative rotational phases according to his or her choice. By the end of the shaking time interval the vibrating mechanism is automatically switched off; the jaws of the gripping unit are automatically (or manually) opened back to the fully open stage, to enable the operator to drive the vehicle towards the next tree the fruits of which are to be harvested.

Controller

An integral controller of a SHF of the present invention is connected to sensors embedded in the system for receiving, storing and processing their signals considering the instantaneous levels of working parameters associated with integral members of the system and/or statuses associated with them. Exemplary are any of the following sensors: proximity sensors, sensors for measuring instantaneous rotational angles and/or speeds, sensors for measuring amplitudes of vibration, such as embedded accelerometers and/or pressure gauges, sensors for measuring a level of fluid such as an hydraulic fluid, sensors for measuring fluid velocity and or capacity, temperature sensors, electrical power, voltage and current, and or any of common sensors that may provide for controlling a level of rotational speed of a driving motor, rotating axes or rotators, and/or a relative rotational phases considering a given pair of rotators. A common programmable processor electrically connected to a number of local controllers of each of the motors respectively driving the eccentric rotators implements the controller of a SHF according to a preferred embodiment of the present invention. A local controller of any of the motors is operative in changing and/or controlling the level of speed of the respective motor as set by the controller of the SHF. A subsystem consisting of a main controller respectively incorporated with one or more local controllers and further linked to respective sensors embedded in a SHF is referred hereinafter as the controller of the SHF. Typically the controller further has a user interface including a displaying screen and operational keys for respectively presenting data and receiving inputted parameters and operational commands to and from the operator. The controller of an SHF of the invention is operative according to the present invention in at least a number of activities selected from the following activities:

- activating motors driving the rotators of the vibrating mechanism to rotate at respective rotational speeds;
- measuring rotational speeds of respective rotators and adjusting their levels to meet respective desired levels;
- measuring rotational angles and adjusting the respective levels of relative rotational phases;
- automatically gripping a trunk or limb of a targeted tree;
- associating time profiles with the measured instantaneous levels of rotational speeds and relative phases;
- deriving a profile of a vibrational mode currently measured;
- calculating the deviations of a currently measured profile from a desired profile of a given vibrational mode;
- measuring instantaneous levels of amplitudes of vibrations and comparing the measured levels with pre-stored thresholds;
- selecting a vibrational mode from a list of vibrational modes recorded in a database;
- generating a vibrational mode as defined by a user, who specifies the magnitudes and directions of rotational speeds of the respective rotators, relative rotational phases and lengths of associated time intervals, and

- recording a selected vibrating profile in a database stored in the memory of the controller.

The controller is further operative in receiving setup and configuration parameters from the operator who inputs their levels by means of the integral operating keys optionally while being prompted through messages displayed across the screen of the operator interface. The controller is further operative in displaying the operator with currently measured working parameters, statuses of internal members of the system, measured parameters, active vibrational modes and calculated data.

EXAMPLE 1

The vibrating mechanism of an exemplary SHF of the invention has three juxtaposed rotators all of which rotate about the same axis. Both outer rotators are of equal weight and have the same eccentricity level. Namely, the center of mass of any of both outer rotators is spaced apart by the same predefined distance from the common axis. One motor whose rotational speed is changeable and controllable drives the intermediate rotator. Another motor having a changeable and controllable rotational speed simultaneously drives both outer rotators. Shaft encoders are respectively connected to the rotating axes each of which drives a respective rotator, as described hereinabove. Clutch couples both rotating axes that respectively drive the outer rotators. For explaining how this SHF provides a user for dynamically changing from one operative vibrational mode into another while the vibrating mechanism is operating, a simple physical model of the vibrating mechanism is first introduced. Any of the rotators involved is represented by a point of mass rotatably connected to the common axis by a weightless shaft the length of which equals the respective eccentricity level. The mass of each point equals the mass of a respective rotator. Both outer rotators rotate at a given rotational speed designated by ω_1. The rotational speed of the intermediate rotator is designated by ω_2. The ratio of these two rotational speeds ω_1/ω_2 has to comply with a predefined value as further described infra. The level of this ratio is referred hereinafter as the relative rotational speed. The product of the magnitude of the mass by the eccentricity level is referred hereinafter as the mass eccentricity product (MEP). The outer rotators are rotationally displaced therefore their relative rotational phase is of such level that the equivalent MEP of both rotators equals a certain value. Following the same physical model, one can represent any pair of synchronously rotating rotators that are rotationally displaced by a fixed relative rotational phase, by a single point of mass the magnitude of which equals the mass of a single rotator and is designated by m_1; the eccentricity level of this equivalent point, which equals its distance from the common axis, is designated by r_1; therefore the equivalent MEP is given by the product m_1r_1; the MEP of the intermediate rotator is similarly derived and designated by m_2r_2. The relative equivalent MEP given by dividing the equivalent MEP of the outer rotators by the MEP of the intermediate rotator has according to the present invention to comply with a predefined value. Namely, the relative rotational phase between the outer rotators is such selected that the quotient $(m_1r_1)/(m_2r_2)$ equals a predefined value as further detailed below. Obviously the intermediate rotator according to the present invention can be replaced by a pair of rotators, which synchronously rotate about the same axis, such that their equivalent MEP equals the product m_2r_2. Equivalent MEP level can be derived according to the invention for a pair of rotators as well as for a single rotator. The value of the quotient of equivalent MEP divided by a level of MEP associated with a single rotator or by another equivalent MEP derived by considering a pair of rotators is referred hereinafter as the relative equivalent MEP.

Reference is now made to **Figs 6 – 17**. Various vibrational modes applicable by means of this exemplary SHF are presented in polar graphs respectively shown in **Figs 6 – 17**. These graphs present torques applied onto a gripped segment of a trunk or limb of a tree while the rotators of the vibrating mechanism rotate in accordance with a respective vibrational mode. The respective magnitudes and directions of the torques exerted by each of the rotating rotators onto the gripped segment of a tree oscillate in time due to the rotational motion of their respective center of masses. The resultant torque that is equivalent to a vector summation of each torque respectively weighted is the main contributor to the vibrational motion of a gripped tree. (Normally, the rotational velocities are such selected that they are considerably distant from resonance frequencies associated with the SHF. Furthermore, the construction of the SHF is such arranged that any parasitic vibrational motion of the SHF itself is considerably smaller compared to the respective oscillating level of the resultant moment exerted by the rotating rotators). The radial coordinate of each point along a plot shown in any of these graphs is proportional to the magnitude of the torque applied. The azimuthal coordinate of such point indicates the direction in which the moment arm (radius) of this torque points. For achieving any of the shown vibrational modes, respective angular velocities of the rotators as well as the relative rotational phase between both outer rotators have to follow certain relations that are detailed in table 1 below.

Fig. No.	$\frac{\omega_1}{\omega_2}$	$\frac{m_1 r_1}{m_2 r_2}$	Comment
6	-0.50	8	Almonds
7	-1.00	1	Oranges
8	-0.71	2	Olives, Cherries
9	-0.20	25	Pecan
10	0.50	2.25	Citrus
11	-0.78	2.1	Walnut
12	1.25	1.25	Citrus
13	0.67	1.25	Citrus
14	0.95	1.25	Citrus

15	0.91	1.4	Citrus
16	-0.50	5.3	Suitable for thinning
17	-0.33	11	Suitable for thinning

TABLE 1 relative rotational speeds and equivalent MEPs providing for generating the vibrational modes respectively shown in Figs 6 – 17.

The required relative rotational speed and relative equivalent MEP providing for generating each virational mode shown in any of the **Figs 6** – **17** is listed in a respective line starting with the number of each figure; relative rotational speeds are listed in the second column headed with $\frac{\omega_1}{\omega_2}$, relative equivalent MEPs are listed in the third column headed with $\frac{m_1 r_1}{m_2 r_2}$, the column headed by " comment" indicate the type of fruit suitably harvested by employing the vibrational mode considered. Any of the vibrational modes respectively shown in **Figs 16** and **17** are suitable for thinning rather than harvesting fruits.

The integral controller of this exemplary SHF activates both motors and adjusts their rotational speed levels to comply with a given relative rotational speed associated with a selected vibrational mode that is pre-stored in the database. Additionally, the relative phase between the outer rotators is adjusted up to the level in which the respective quotient of the MEPs converges within a predefined convergence range to the level of the relative equivalent MEP that is pre-stored in the database. To change from one vibrational mode to another, the setup parameters, associated with a currently operative vibrational mode are accordingly changed automatically or by an operator command; the transfer to the new vibrational mode is automatically accomplished while the vibrating mechanism is continuously operating; by similarly adjusting the respective rotational speeds and relative rotational phase. Alternatively, the operator may change any working parameter of the set of working parameters of the vibrating mechanism, including the rotational speeds of any of the motors and the relative rotational phase between the outer rotators, by manually changing any of the parameters including the two rotational speeds and the relative rotational phase. Such change effected considering any of these parameters brings about a new vibrating mode that is different from the previous one.

EXAMPLE 2

A SHF having a distributed vibrating unit in accordance with an embodiment of the present invention has two sets of eccentric rotators. One set includes two coaxial rotators each of which is of the same weight and eccentricity. Both rotators are driven by the same motor its rotational speed is controlled. Shaft encoder connected to each of the rotating axes of the respective rotators provides for controlling the relative rotational phase between these rotators. These rotating axes are mutually coupled by means of a clutch as described above; thereby both rotators are synchronously rotatable at the same rotational speed (magnitude and direction). The other set has only one eccentric rotator whose instantaneous rotational angle is measured by means of additional shaft encoder. This rotator is driven by another motor its rotational speed is controlled. The two sets of rotators are respectively mounted onto two different clamping jaws, such that both axes about which the respective set of rotators rotates are symmetrically disposed at both sides of the y-z plane of a coordinate system, the x-y plane of which is parallel to the planes (all of which are mutually parallel) in which each rotator respectively rotates, and both axes of rotation are contained in the x-z plane. Any pair of rotators having the same rotational speed and common axis can be represented by an equivalent rotating point of mass having any desired eccentricity level in the range [0,<r>], where <r> is the mean value of the eccentricity levels of both rotators. Therefore an equivalent MEP associated with the equivalent point of mass considering this pair of rotators can be adjusted to a desired level by adjusting the relative rotational phase between these rotators when both rotators rotate at a given rotational speed. The equivalent MEP of the rotator of the other set of rotators is similarly derived as described hereinabove. By suitably selecting the respective rotational speeds such that the quotient $\frac{\omega_1}{\omega_2}$ equals a given value, where ω_1 is the level of rotational speed of the pair of rotators and ω_2 is the respective level of the other rotator; and further adjusting the relative rotational phased between the pair of rotators to get a respective value of the relative MEP, this distributed vibrating mechanism is activated to vibrate in accordance with a desired vibrational mode, such as any of the modes shown in **Figs 6-17**. Additionally the vibrational mode of SHF can be changed while the vibrating mechanism continuously operating in a similar manner as described in example 1 above.

The rotators of the pair need not according to the present invention have the same axis of rotation. A distributed vibrating mechanism of a SHF according to another embodiment of the present invention has a single eccentric rotator mounted on one clamping jaw and driven by a respective motor the rotational speed of which is controllable as the respective rotator of the vibrating mechanism described above. The set of two coaxial rotators that is mounted on a different clamping jaw of the SHF described above is replaced by a set including two rotators of the same weight and eccentricity. The respective axes of rotation of both rotators are symmetrically disposed relative to the x-z plane of the same coordinate system described above. These rotators are driven by the same motor the rotational speed of which is controlled. A clutch controlled by the controller of the SHF provides for momentarily decoupling one of these rotators from its driving motor providing for adjusting their relative rotational phase. Three shaft encoders provide for measuring the instantaneous rotational angles of all the three rotators respectively. By employing the same physical model in which each rotator is presented by a respective point of mass connected to the respective axis with a weightless shaft, one can present the resultant torque that is equivalent to a weighted vector summation of the torques exerted by each rotator of the pair of rotators with the respective torque exerted by the equivalent point of mass associated with this pair. Therefore this distributed vibrating mechanism can be similarly operated by suitably selecting the levels of the relative rotational speed and relative equivalent MEP to apply any desired vibrational mode, such as the modes shown in any of the **Figs 6-**

17. Additionally the vibrational mode of SHF can be changed while the vibrating mechanism continuously operating in a similar manner as described in example 1 above.

Furthermore one can get by similarly grouping pairs of rotators out of all the rotators of a vibrating mechanism respective equivalent rotating mass points the associated levels of equivalent MEPs of which are similarly derived. Therefore by hierarchically grouping pairs of equivalent mass points, one can finally get two representative points of mass associated with two respective levels of equivalent MEPs. Additionally by suitably selecting the rotational speeds in which each rotator rotates one can bring the relative rotational speed associated with the two representative points of mass to match with the respective level of a desired vibrational mode. Activation of a vibrational mode is accomplished by rotating each rotator at such derived rotational speed and controlling such selected relative rotational phases associated with the respectively selected pairs of rotators. Furthermore any of such activated vibrational modes can be continuously changed while the vibrating mechanism of this SHF is operating. Such changing is accomplished by modifying at least one working parameter of the parameters including rotational speeds of the rotators, relative rotational phases associated with pairs of rotators.

CLAIMS

1. A shaker for harvesting fruits (SHF) comprising
   - a vibrating mechanism for generating mechanical vibrations, wherein said vibrating mechanism comprises at least three rotators, at least two of which rotatably synchronized, and
   - a controller for at least controlling the relative rotational phase associated with said at least two rotators.

2. A SHF as in claim 1, wherein said relative rotational phase is changeable.

3. A SHF as in claim 1, wherein the level of rotational speed of at least one of said at least three rotators is changeable.

4. A SHF as in claim 3, wherein said controller is operative in controlling said level of rotational speed.

5. A SHF as in claim 1, wherein the center of mass of each of said at least three rotators spaced apart from its respective axis of rotation by a predefined distance respectively.

6. A SHF as in claim 1, wherein said at least two of said at least three rotators rotatable about a common axis.

7. A SHF as in claim 1, further comprising at least one clamping jaw, and wherein said at least one clamping jaw has a face structured and arranged to enclose a segment of an engaged tree.

8. A SHF as in claim 6, wherein said at least one clamping jaw comprises a proximity sensor.

9. A method for changing a vibrational mode of a shaker for harvesting fruits (SHF), wherein said SHF comprises at least three of eccentric rotators, and wherein said varying effected while said eccentric rotators continuously rotate, said method comprising controllably varying the level of the relative rotational phase associated with at least one pair of rotators of said at least three rotators.

10. A method as in claim 9, further comprising adjusting the level of said relative rotational phase to a level complying with a level of the equivalent mass eccentricity product (MEP), which is the first level of equivalent MEP, derived for said at least one pair of rotators, wherein said first level of MEP is given by dividing a second level of equivalent MEP derived by considering at least one rotator of said at least three rotators by a predefined constant, and wherein said at least one rotator is different from any rotator of said at least one pair of rotators.

11. A method as in claim 9, further comprising rotating two of said at least three rotators at rotational speeds the quotient of the respective levels of which comply with a given level of relative rotational speed.

12. A method as in claim 9, wherein each of said at least three rotators rotatable about a common axis.

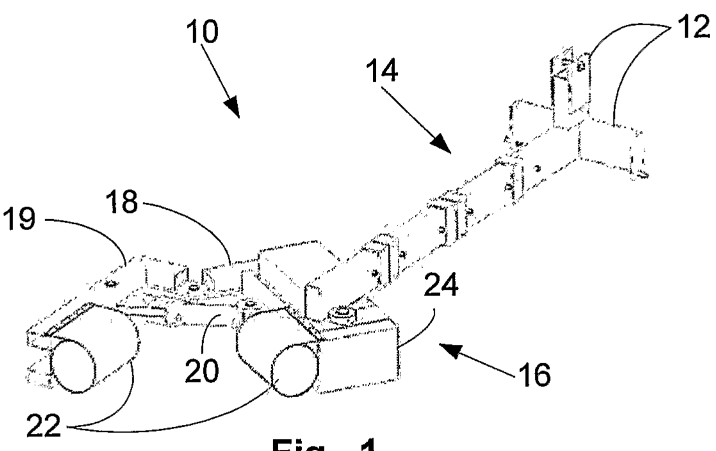

Fig. 1

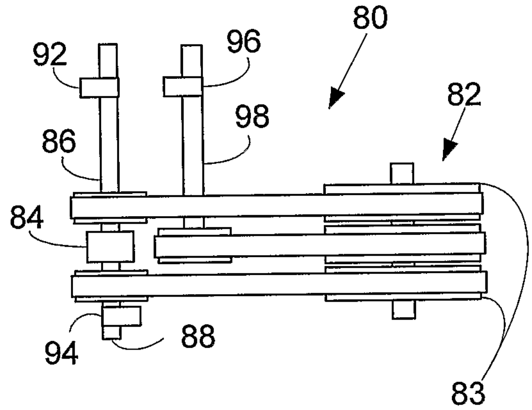

Fig. 4

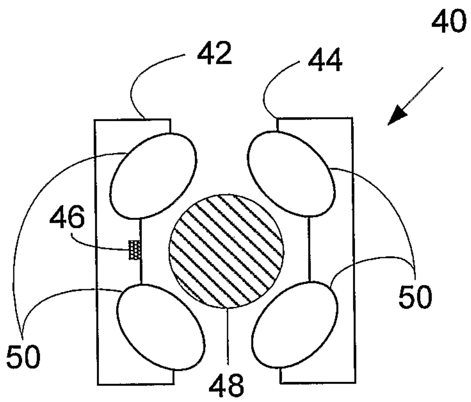

Fig. 2

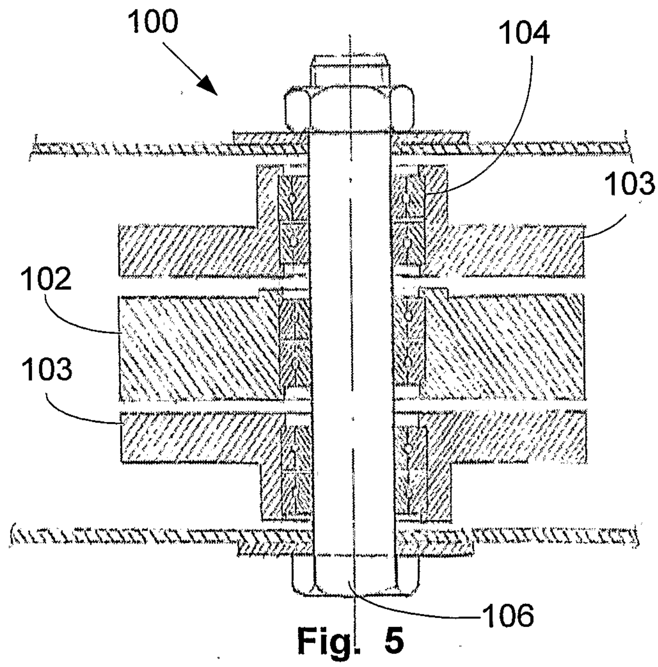

Fig. 5

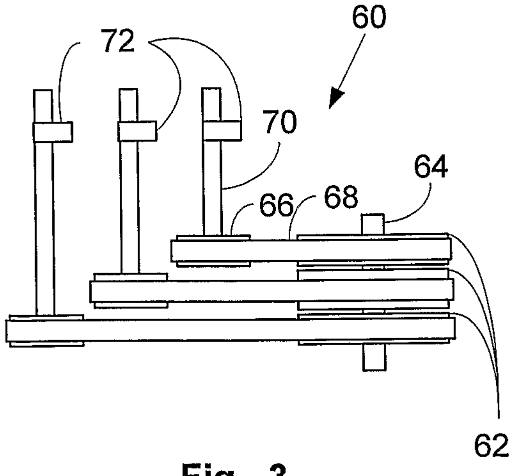

Fig. 3

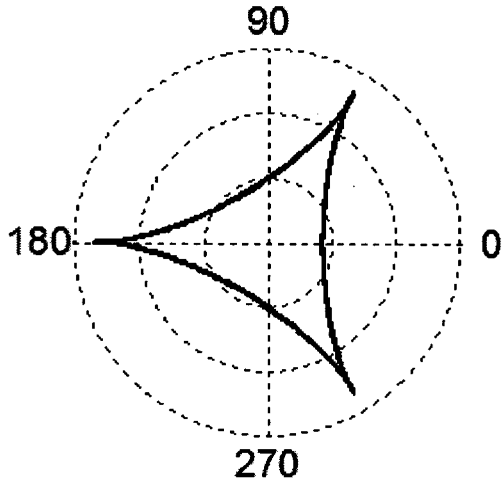

Fig. 6

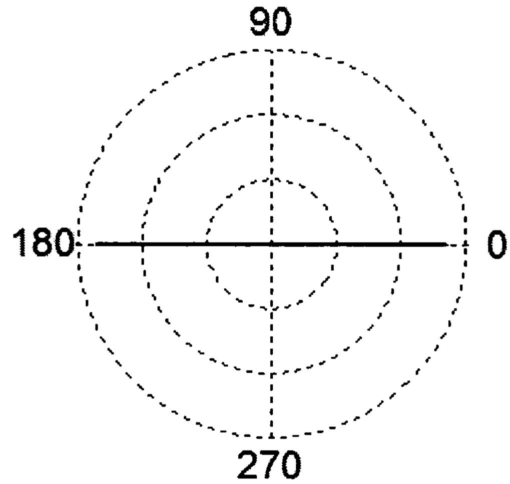

Fig. 7

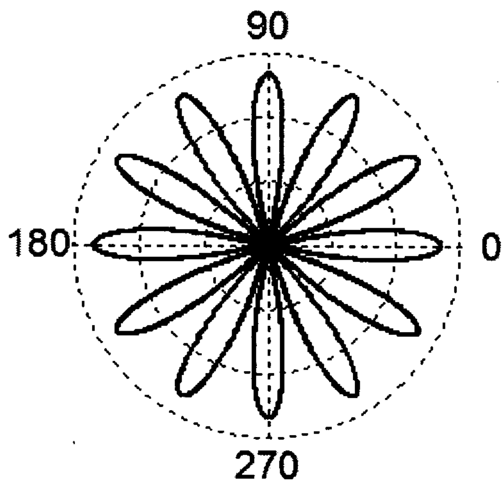

Fig. 8

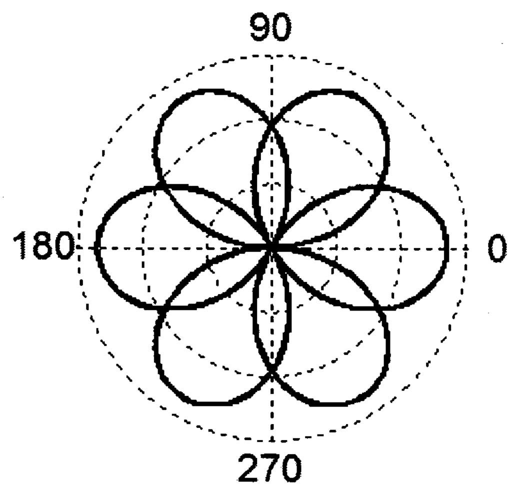

Fig. 9

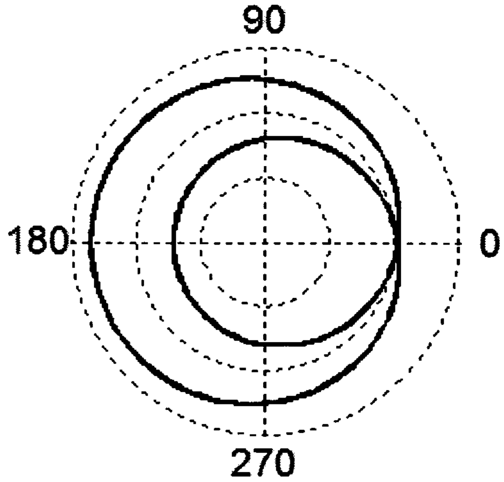

Fig. 10

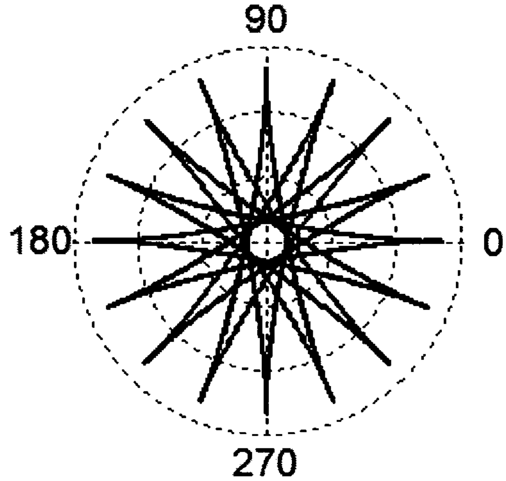

Fig. 11

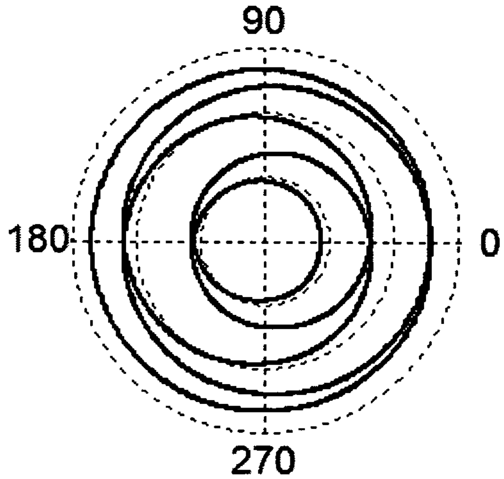

Fig. 12

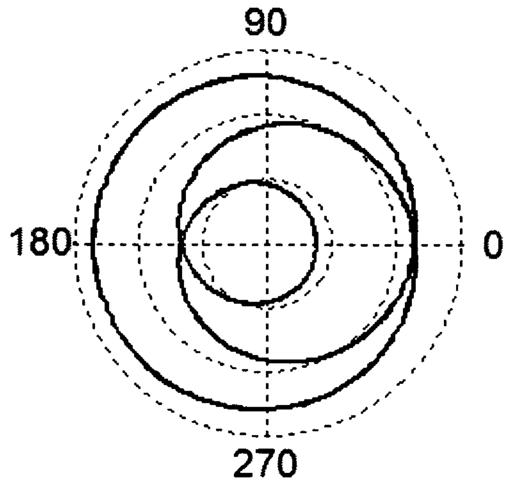

Fig. 13

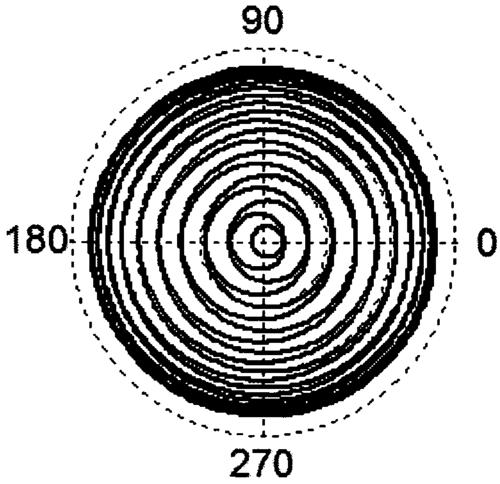

Fig. 14

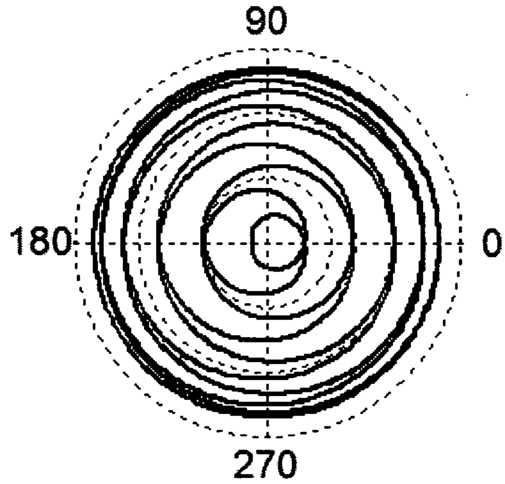

Fig. 15

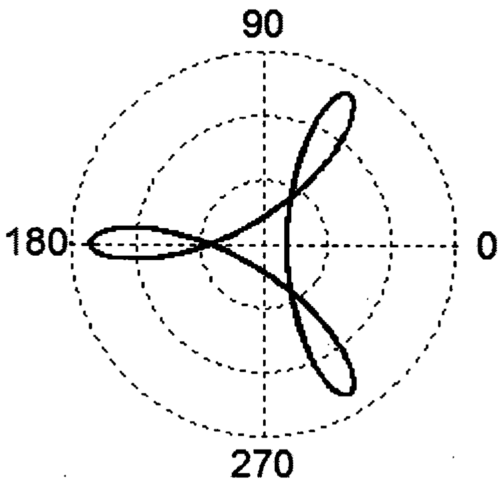

Fig. 16

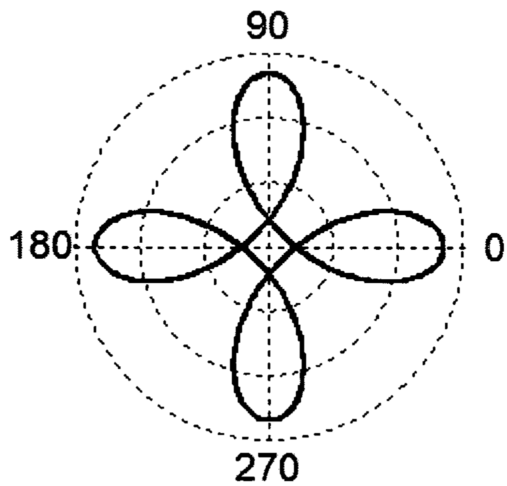

Fig. 17