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(56) Documents Cited
FR 002261075 A **US 5156802 A**
US 4466543 A **US 4212398 A**
US 3127016 A

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UK CL (Edition T) **A1F** FEB FEH, **G1G** GPCR GPGX GPKA
INT CL^7 **A01D** 33/04 33/08, **B07C** 5/34, **G01N** 19/08
Other: **EPODOC, JAPIO, WPI**

(54) Abstract Title
Classification of objects by their impact characteristics upon an element

(57) A method and means of classifying a succession of objects 13 moving along a defined path comprises causing the objects 13, one at a time, to strike an element 22 such that it vibrates. The properties of an incident object 13 are determined from a vibration characteristic of the struck element 22. The rate of decay of the vibration of the said element may be used. The detected properties are then used to select or reject each object 13. The defined path may be a conveyor 10. The struck element 22 may be a rod arranged partly in the path of the objects 13. The objects 13 may be agricultural produce such as a beet root crop. The classification system may separate good beets from deteriorated beet, stones and clods of earth. A gate 17 may be used to perform the select, reject process.

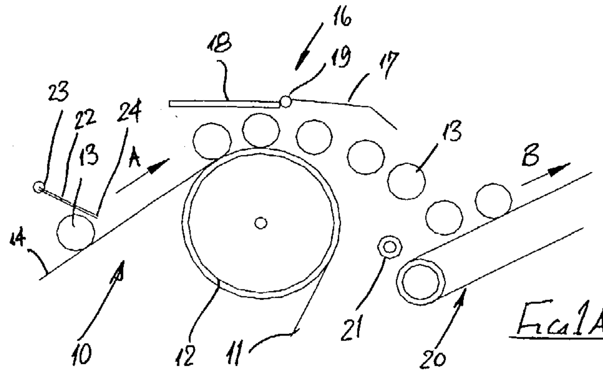

Fig 1A.

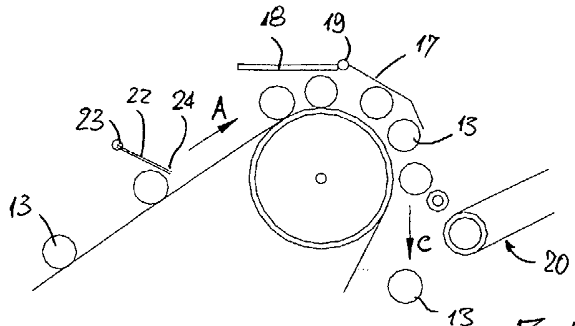

Fig 1B

GB 2 377 019 A

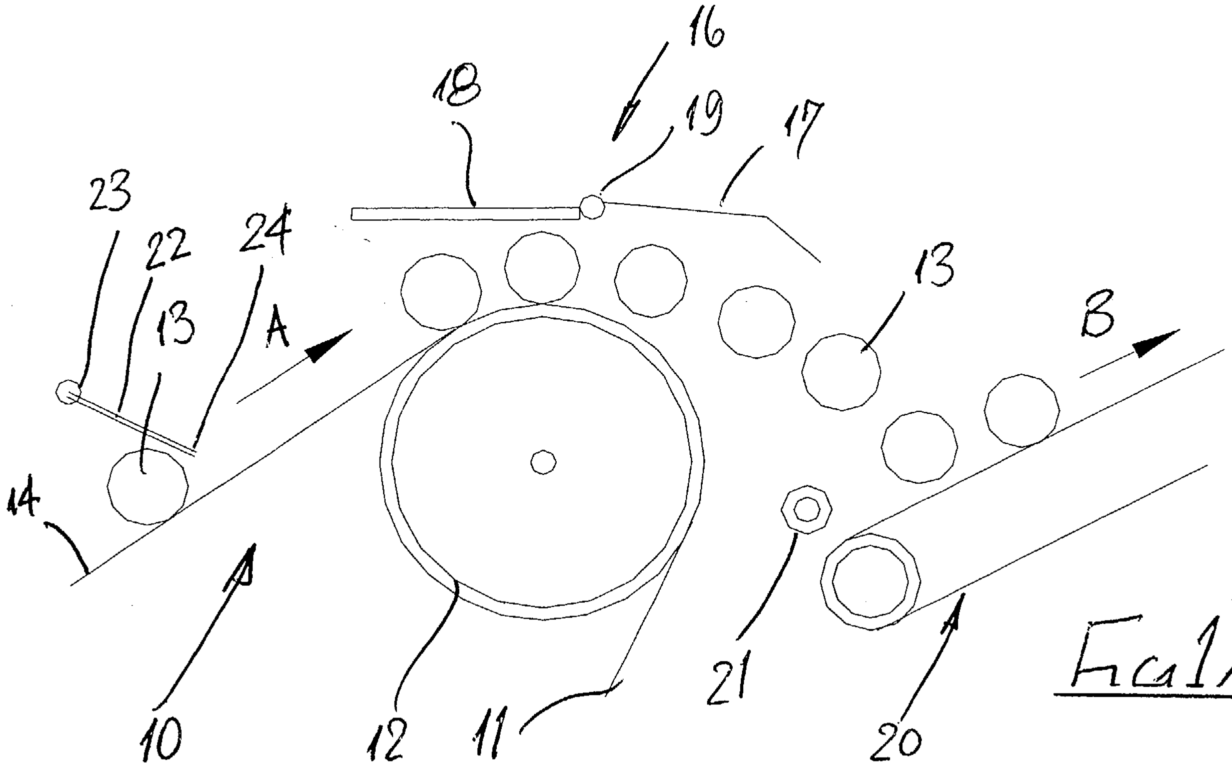
16
18
19
17
23
22
24
13
A
13
B
14
10
12
11
21
20

Fig 1A.

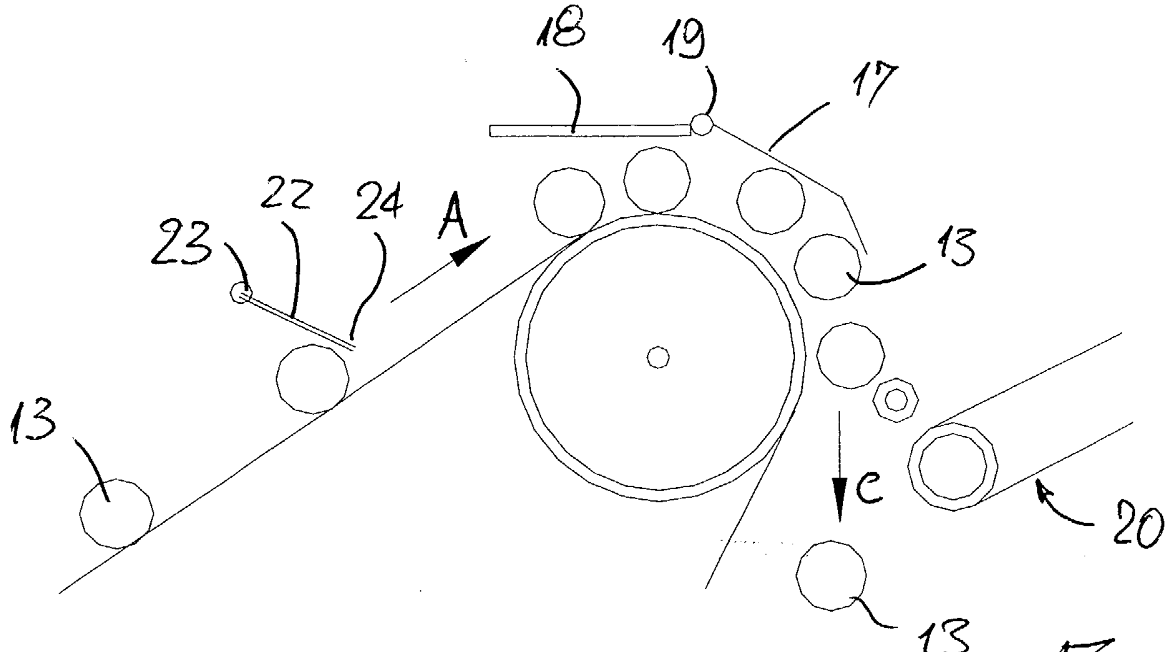
18
19
17
22
24
A
23
13
13
C
20
13

Fig 1B

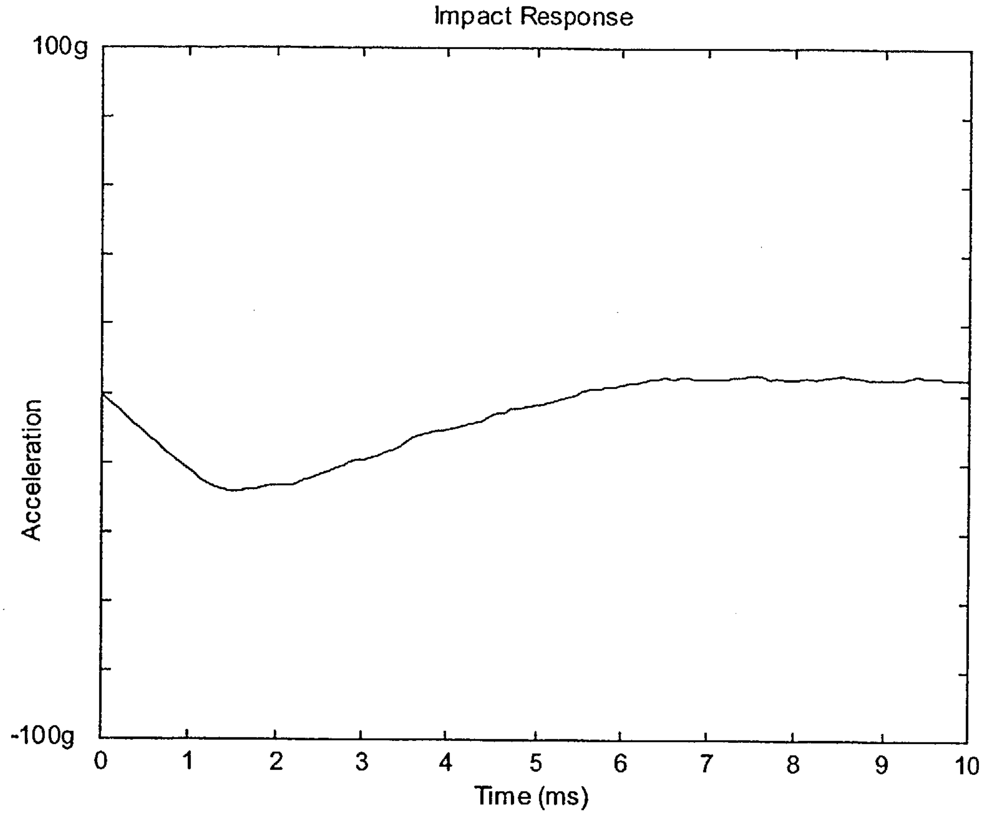
Impact Response
100g
-100g
Acceleration
0
1
2
3
4
5
6
7
8
9
10
Time (ms)

FIG 4

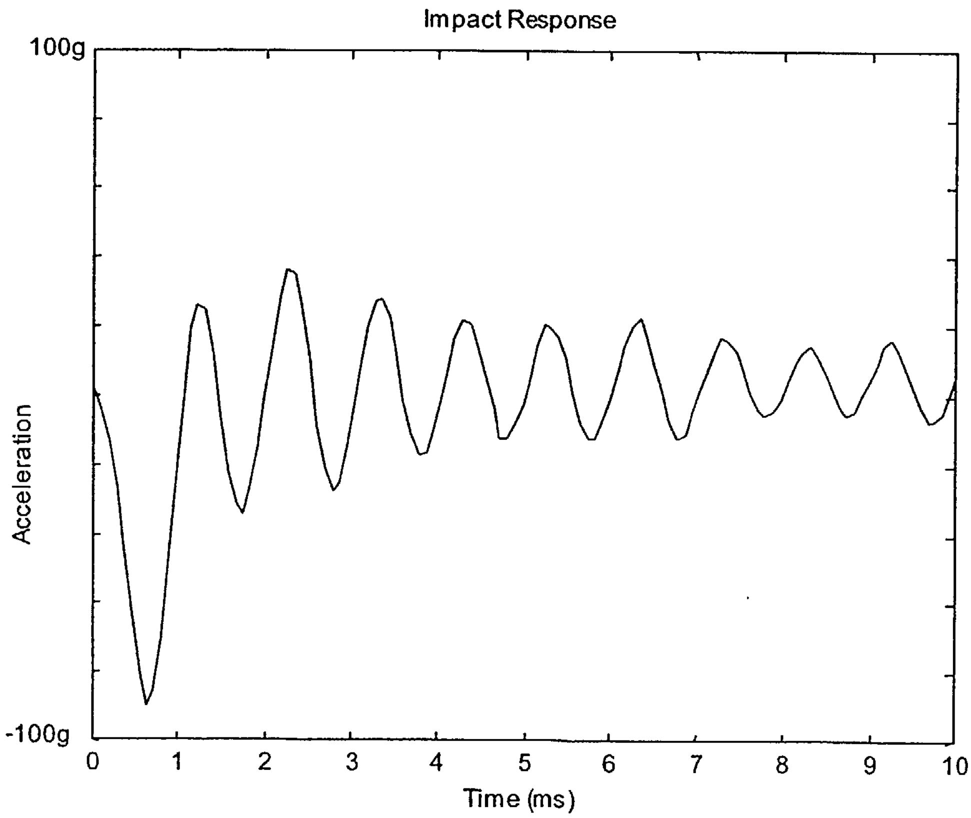
Impact Response
100g
-100g
Acceleration
0
1
2
3
4
5
6
7
8
9
10
Time (ms)

FIG 2

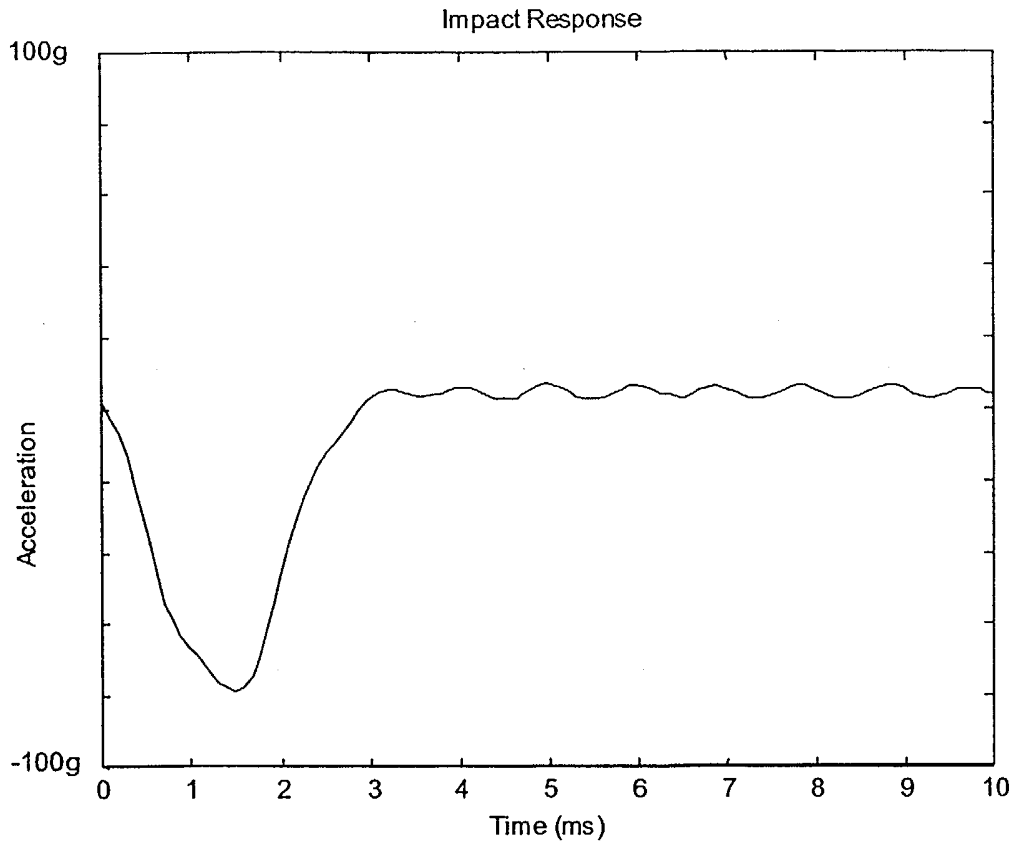
Impact Response
100g
-100g
Acceleration
0
1
2
3
4
5
6
7
8
9
10
Time (ms)

FIG 3

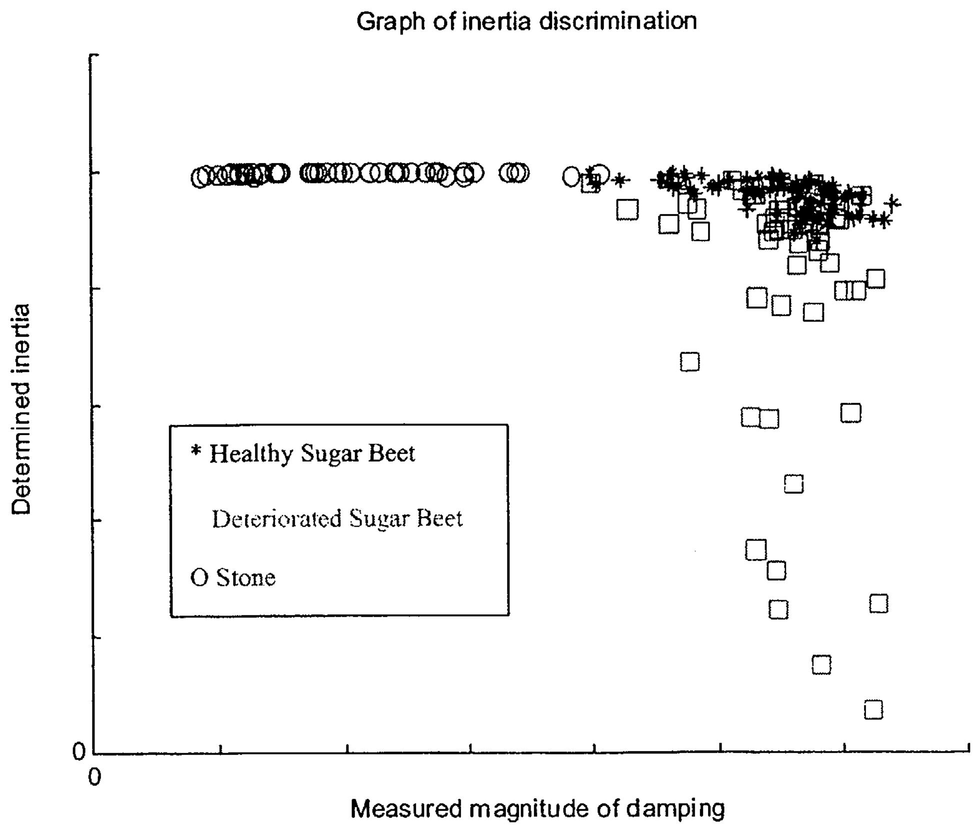
Graph of inertia discrimination
Determined inertia
0
0
Measured magnitude of damping
* Healthy Sugar Beet
Deteriorated Sugar Beet
O Stone

FIG 5

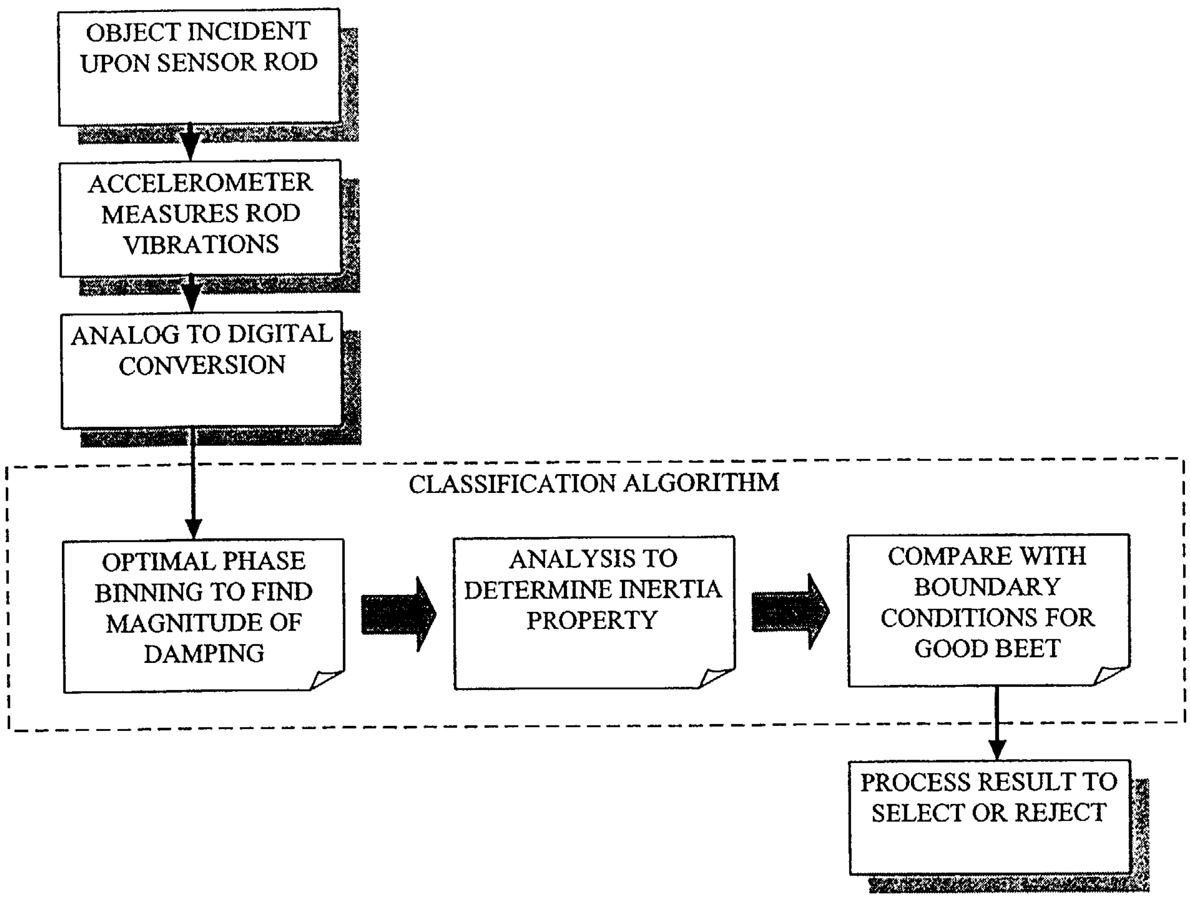
OBJECT INCIDENT UPON SENSOR ROD
ACCELEROMETER MEASURES ROD VIBRATIONS
ANALOG TO DIGITAL CONVERSION
CLASSIFICATION ALGORITHM
OPTIMAL PHASE BINNING TO FIND MAGNITUDE OF DAMPING
ANALYSIS TO DETERMINE INERTIA PROPERTY
COMPARE WITH BOUNDARY CONDITIONS FOR GOOD BEET
PROCESS RESULT TO SELECT OR REJECT

FIG 6.

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CLASSIFICATION OF OBJECTS

This invention relates to a method of classifying a succession of objects moving along a defined path, and in particular (but not exclusively) a method of classifying items of grown produce. The invention further relates to apparatus for performing such methods.

The present invention is primarily concerned with the classification of agricultural produce, and especially root crops. However, the invention is applicable to the classification of other objects and so, though the invention will primarily be described with reference to the classification of agricultural produce, nevertheless the invention is not to be regarded as being limited thereto.

There have been many proposals for methods of, and apparatus for, performing the classification (or grading) of items of grown produce. Most of these proposals aim at determining some particular property of the produce and then making a decision as to the appropriate classification for each item, dependent upon the determined property. For example, a classifying apparatus (or grader) may determine one or more of the weight, size and colour of each item of produce and then direct that item into an appropriate lane of the apparatus to a designated destination, dependent upon the value of the or each monitored property. At its simplest, such apparatus may have two lanes or destinations, one for selected items and the other for rejected items, though graders are known having many such lanes or destinations, in order to perform the required grading of the items.

There is a particular problem with the classification of harvested sugar beet. Harvesting is performed from the autumn through to the winter when the ground may be wet and difficult to work, so that considerable quantities of soil may adhere to the beet lifted from the ground. The harvested beet may vary considerably in size and it is likely that stones and other unwanted objects are lifted along with the beet themselves. If that other matter is of a size which falls within the acceptable size range for the beet, it will not be rejected by a simple screening process which is usually performed at the time of harvesting the beet.

A further problem arises if the beet are harvested after the first frosts have occurred. Sugar beet can be damaged by severe frosts and there is currently no easy and reliable automated process available for distinguishing sound beet from frost-damaged, old and diseased beet, all of which latter are referred to hereinafter as "deteriorated beet".

In the case of the harvesting of sugar beet, the usual procedure is that a farmer locally processes the lifted beet by a simple hand screening operation. The beet are then transported in bulk to a sugar refiner, where they are further cleaned, usually by washing, and graded before being subjected to the established processes to extract the sugar. These cleaning and further operations are performed under factory conditions, where currently acceptable results can be achieved. Consequent upon the better cleaning of the beet, the sugar refiner has large quantities of soil, stones and other matter to dispose of and so exerts pressure on each grower to take measures to clean and classify his own produce more effectively, as well as to remove soil, stones and other matter, before delivering the beet to the refiner.

Generally, the refiners impose financial penalties for poorly cleaned and classified beet, determined by subjecting a bulk load from a grower to small-scale spot sampling. If the sample is found to contain more than certain pre-defined quantities of any one or more of soil, stones, or deteriorated beet, then the payment to the grower for his entire bulk load will be significantly reduced. There is thus a considerable demand for a grower to be able to perform better cleaning and classification of the beet as harvested, before they are dispatched to a sugar refiner.

It is possible for sugar beet to be classified locally, after harvesting, by supplying the beet to a picking table, or transporting the beet along a conveyor, and subjecting the beet to a visual inspection with the aim of manually removing reject objects. However, such processes are inefficient, labour intensive and so expensive to perform. Further, though the processes may be performed in the field, it is preferred to carry out manual classification under protective cover so further adding to the cost. Thus, the cost to a grower of better grading his beet before dispatch to a refiner must be weighed against the reduction in payment to the grower by the refiner, for sending to the refiner bulk loads which fall short of the standards set by the refiner.

The present invention aims at providing both a method of and apparatus for classifying objects moving along a path, and in particular a method of and apparatus for classifying (or grading) items of grown produce such as sugar beet, which method and apparatus may be performed rapidly and effectively to discriminate objects to be selected from those to be rejected, including rejecting unwanted matter entrained with the objects.

According to one aspect of this invention, there is provided a method of classifying a succession of objects moving along a defined path, comprising the steps of:

– causing the objects to be incident one at a time upon an element with known resonant frequency so as to excite vibrations in the element;

– determining the magnitude of the damping of the vibrations during excitation of the element;

– determining the relative inertial properties of the objects incident on said element from the determined magnitude of the damping of the vibrations; and

– deciding whether to select or reject each object on the basis of its determined relative inertial properties.

According to a second aspect of this invention, there is provided apparatus for classifying a plurality of objects, comprising:

– means to advance the objects in succession along a defined path;

– an element with known resonant frequency lying in the path of advancement of the objects whereby the objects are incident one at a time upon the element so as to excite vibrations therein;

– means to determine the magnitude of the damping of the vibrations during excitation of the element;

– means to determine the relative inertial properties of the objects incident upon said element from the determined magnitude of the damping of the vibrations; and

– a rejection unit to reject objects from the path which unit is controlled on the basis of the determined relative inertial properties of the objects.

It will be appreciated that both the method and apparatus of this invention particularly lend themselves to the classification of agricultural produce and especially root crops such as sugar beet, and so will hereinafter be described solely with reference to this intended purpose. However, the method and apparatus may be used for the classification of other objects, and is not to be regarded as limited to agricultural uses.

In performing the present invention, each object of the succession thereof is caused to be incident on an element with known resonant frequency, so as to excite vibrations in that element. Such an element preferably is in the form of a rod which lies in the path of movement of the objects so that each object of the succession thereof will, in turn, be incident on the rod. The particular material from which the rod is made, as well as its physical dimensions, may conveniently be determined empirically having regard to the expected size, weight and inertia of the objects which are to be incident on the rod, but typically a rod of a steel alloy and having a hollow cross section may conveniently be employed.

An accelerometer may be associated with the element, in order to permit the determination of the magnitude of the damping of the vibrations of the element. Such an accelerometer must have a fast response time in order to sense the vibrations of the element and produce an accurate analogous electrical output.

The relative inertial properties of the objects are determined from the magnitude of the damping of the vibrations of the element. In the case of a very hard object (such as a rock) the envelope of the vibrations excited in the element is different from the envelope of the vibrations excited in the element by softer objects including items of grown produce such as sugar beet. It can be seen from the examples of graphical evidence below that the waveform produced by sugar beet is different from that produced by a hard object such as a rock insofar as the soft object waveform does not display the simple harmonic attack and decay envelope characteristic of a hard object. Instead the vibrations of the element are more complex when a soft object such as a sugar beet is incident upon it. This gives rise to the characteristic rise and fall envelopes of items of grown produce such as sugar beet. With items of grown produce such as sugar beet, the rate and limits of the vibrations of the element are proportional to the magnitude of damping associated with the produce.

In view of the above, the selection or rejection decision for each object incident upon the element may additionally take into account the magnitude of the damping of the vibrations of the element determined during excitation of the element, as well as the determined relative inertial properties. In this way, excellent discrimination of sound items of grown produce can be achieved, with rejection of unwanted matter such as hard objects and deteriorated produce.

Preferably, the magnitude of the damping of the vibrations of the element is determined by analysing the output of the accelerometer, to determine the relative powers of the frequency components of the vibrations of the element. The preferred method of analysis is that known as optimal phase binning, which allows the power of frequency components of signals to be determined rapidly in real time, faster than can be achieved with fast Fourier transforms. With optimal phase binning, the times at which data samples are taken need not be known exactly, and optical phase binning can be used equally effectively with data samples taken either at regular intervals in time or at known times. Optimal phase binning is described in *The Processing of Data from Multi-Hydrophone Towed Arrays of Uncertain Shape* (Geoffrey William Sweet; University of Southampton Doctoral Dissertation, 1993, p 89ff.) and in *A New Method of Locating Sources of Acoustic Radiation in Three-Dimensional Space* (Geoffrey William Sweet; Proceedings of The Institute of Acoustics 1999 Vol. 21, Part 8, p 177ff.). By using such an analysis technique, decisions may rapidly be made, as to whether to accept or reject an object incident upon the element.

The means to advance the objects along the defined path should be selected having regard to the particular objects to be subjected to the classification method. For example, in the case of grown produce such as sugar beet, the items may be moved along the defined path by a simple mechanical conveyor.

By way of example only, one specific embodiment of method and apparatus according to the present invention will now be described in further detail, reference being made to the accompanying drawings, in which:-

Figures 1A and B diagrammatically illustrate the principal mechanical components of the embodiment of classification apparatus of this invention;

Figures 2, 3 and 4 show the accelerometer output respectively when a stone, healthy sugar beet and deteriorated sugar beet are incident upon the sensing element;

Figure 5 illustrates the discrimination between three different types of objects with respect to their inertial properties; and

Figure 6 is a flow chart of the processing undertaken in performing the embodiment of this invention.

In this description of the preferred embodiment, the items to be classified by the apparatus are sugar beet, to which reference will exclusively be made in the following.

Referring initially to Figures 1A and 1B, there is shown part of the embodiment of apparatus arranged to perform the classifying method of the present invention. This apparatus comprises a conventional belt conveyor 10 having a resilient endless belt 11 passing around an upper idler roller 12, there being a lower driven roller (not shown) disposed at a position spaced from the idler roller, to make up the conveyor in a manner well known in the art. A feed hopper arrangement (also not shown) is provided adjacent the lower driven roller in order to supply a succession of individual beet 13 on to the upper run 14 of the conveyor whereby the items are advanced in the direction of arrow A.

At the upper end of the belt conveyor 10 is provided a select/reject mechanism 16 including a gate 17 pivoted to a frame component 18 for rotational movement about shaft 19, between select and reject positions shown respectively in Figures 1A and 1B. When the gate 17 is in the select position, beet 13 pass over the idler roller 12 and are projected on to the inlet end of a further belt conveyor 20 so as to be carried along the upper run of that conveyor in the direction of arrow B. On the other hand, when the gate is in the reject position (Figure 1B) beet are deflected downwardly closely to follow a greater part of the cylindrical surface of the idler roller 12 and then to fall generally vertically downwardly, as shown by arrow C. A selector bar or roller 21 serving as a separation device is suitably positioned at the inlet end of the further belt conveyor 20 to assist the selection or rejection process by ensuring that rejected beet follow the path shown by arrow C, whilst encouraging selected beet to fall on to the further conveyor belt 20 to be carried in the direction of arrow B.

A suitable mechanism is provided to operate the gate 17 in a timed relationship to the advancement of beet along the conveyor 10, whereby the gate may be set at the appropriate position for each beet reaching the upper end of the conveyor. Such a mechanism must be capable of operating the gate relatively quickly, particularly having regard to the anticipated through-put of the apparatus in classifying beet.

The classification is performed by determining the relative inertial properties of each beet advancing along the conveyor 10 in the direction of arrow A. This is achieved by arranging above the belt 11 a sensing element 22 in the form of an elongate rod held at one end 23 and disposed so that its other end 24 is in the path of advancement of the beet. Each beet in turn is incident upon the lower other end 24 of the rod, so exciting that rod to vibrate.

In a typical embodiment the rod 23 comprises a steel bar of square hollow section. The bar is 350mm long, with cross-sectional dimensions of

40mm x 40mm and having a wall thickness of 3.2mm. It is possible to calculate the resonant frequency of such a rod and typically is about 1000Hz. Depending upon the items to be sorted, the speed of sorting and other factors, the resonant frequency for the rod may be selected to lie in the range of 800Hz to 1500Hz.

A micro-sensitive accelerometer (not shown) is mounted within the rod toward the free end thereof and provides an electrical output to a micro-processor (also not shown) which analyses that output, by converting the analogue electrical signal into a digital signal and then determining the power of the frequency components of the accelerometer output, for example by the process of optimal phase binning, as referred to hereinbefore. From that, the magnitude of the damping of the vibrations of the rod can be determined.

Optimal phase binning is a known technique which allows the frequency powers of a signal to be calculated rapidly in real time. The technique involves averaging sample data into three equally spaced time bins. For each frequency to be tested, the bins are one-third of the cycle time associated with that frequency. The sum of the squared averages gives a spectrum power for the tested frequency. This can be repeated for a plurality of test frequencies to produce a frequency spectrum. In cases where specific frequency powers are required, this is an exceptionally fast method for spectrum analysis.

From the frequency spectrum analysis achieved by the optimal phase binning technique, the magnitude of the damping of the vibrations of the rod can be determined, and in turn so can be the relative inertial properties for each beet to allow a decision to be taken as to whether to accept or reject each beet.

The process is shown in the flow chart of Figure 6. As illustrated, the optimal phase binning technique is performed following each excitation of the rod by an incident beet, to find the magnitude of the damping of the vibrations. That is analysed to determine the inertial property of the beet and a comparison is performed with pre-determined boundary conditions for good beet. The output of the comparison is used to produce a select or reject signal, which in turn controls the operation of the gate 17, in a timed relation to the advancement of beet along the conveyor 10 such that the gate will be operated to select or reject that particular beet, as appropriate.

A typical output of the accelerometer when a hard object such as a stone or a rock is incident upon the element 22 is shown in Figure 2. As can be seen, there is negligible damping of the vibrations of the element caused by the stone. A healthy sugar beet striking the element significantly damps the vibrations of the element, as shown in Figure 3. A beet which has deteriorated in quality, and so which is soft and lacks crispness, damps the vibrations of the element 22 to a very great degree, as shown in Figure 4. Then, by applying optimal phase binning on the output of the accelerometer, the results shown in Figure 5 can be obtained. These results readily lend themselves to the separation of stone and deteriorated sugar beet from the healthy sugar beet.

Rocks and stones are discarded by rejecting all objects which apply a low magnitude of damping to the vibrations in the sensing element. Objects which have a low determined relative inertia are rejected as deteriorated sugar beet.

The micro-processor, having performed the analysis on the output of the accelerometer, then provides a decision signal which is synchronised with the advancement of the beet along the conveyor 10, to cause operation of the gate 17 when beet is to be rejected, but otherwise permitting selected beet to be received on the further conveyor 20 to be advanced in the direction of arrow B.

The method described above enables items of healthy root crop (such as sugar beet) to be distinguished easily from unwanted objects such as stones or clods of earth and deteriorated sugar beet. The inertial properties of the latter are appreciably different from those of healthy root crops, and so the assessment of the inertial property of items incident upon the sensing element allows the distinguishing of acceptable produce from other material, in a continuous through-put process.

CLAIMS

1. A method of classifying a succession of objects moving along a defined path, comprising the steps of:

– causing the objects to be incident one at a time upon an element with known resonant frequency so as to excite vibrations in the element;

– determining the magnitude of the damping of the vibrations during excitation of the element;

– determining the relative inertial properties of the objects incident on said element from the determined magnitude of the damping of the vibrations; and

– deciding whether to select or reject each object on the basis of its determined relative inertial properties.

2. A method as claimed in claim 1, wherein the selection or rejection decision for each object involves taking into account the magnitude of the damping of the vibrations of the element determined during excitation of the element by the incidence of that object upon the element.

3. A method as claimed in claim 1 or claim 2, wherein the objects to be classified comprise items of agricultural produce, to be classified dependent upon the quality of each item.

4. A method as claimed in claim 3, wherein the items of agricultural produce comprise root crops.

5. A method as claimed in any of the preceding claims, wherein the element is in the form of a rod which at least partly lies in the path of movement of the objects.

6. A method as claimed in any of the preceding claims, wherein the element is associated with an accelerometer the output of which is used to determine the magnitude of the damping of the vibrations of the element.

7. A method as claimed in claim 6, wherein the magnitude of the damping of the vibrations is determined from the relative powers of the frequency components of the vibrations of the element.

8. A method as claimed in claim 7, wherein optimal phase binning is used to determine the magnitude of the damping of the vibrations.

9. A method as claimed in any of the preceding claims, wherein the objects are moved along the path by a conveyor.

10. method of classifying a succession of objects moving along a defined path as claimed in claim 1 and substantially as hereinbefore described with reference to the accompanying drawings.

11. Apparatus for classifying a plurality of objects, comprising:

– means to advance the objects in succession along a defined path;

– an element with known resonant frequency lying in the path of advancement of the objects whereby the objects are incident one at a time upon the element so as to excite vibrations therein;

– means to determine the magnitude of the damping of the vibrations during excitation of the element;

– means to determine the relative inertial properties of the objects incident upon said element from the determined magnitude of the damping of the vibrations; and

– a rejection unit to reject objects from the path which unit is controlled on the basis of the determined relative inertial properties of the objects.

12. Apparatus as claimed in claim 11, wherein the element is in the form of a rod constrained at or adjacent one end and disposed so that the other end of the rod lies in the path of advancement of the objects to be incident thereupon.

13. Apparatus as claimed in claim 11 or claim 12, wherein the determining means comprises an accelerometer associated with the element and arranged to produce an electrical output dependent upon the sensed vibrations of the element.

14. Apparatus as claimed in claim 13, wherein the means to determine the magnitude of the damping of the vibrations comprises means to determine the power of the frequency components of the sensed vibrations, and to produce an inertial classification dependent thereon.

15. Apparatus as claimed in any of claims 11 to 14, wherein the means to advance the objects comprises a conveyor.

16. Apparatus as claimed in any of claims 11 to 15, wherein the rejection unit comprises a gate mechanism operable between select and rejection settings, the gate mechanism being controlled dependent upon the determined relative inertial properties of the objects.

17. Apparatus for classifying a plurality of objects as claimed in claim 11 and substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

Application No: GB 0108938.2
Claims searched: 1 - 17

16

Examiner: John Watt
Date of search: 25 October 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): A1F (FEH, FEB); G1G (GPCR, GPGX, GPKA)

Int Cl (Ed.7): A01D 33/04, 33/08; B07C 5/34; G01N 19/08

Other: Online: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	FR 2261075 A	(ETEL S.A.) see fig.1	1, 3, 4, 6, 9, 11, 13, 15 & 16 at least
X	US 5156802	(ROBERTSON ET AL) see fig.1	1 & 11 at least
X	US 4466543	(ZWAHLEN ET AL) see whole document	1, 3, 4, 9, 11 & 15
X	US 4212398	(PARKER ET AL) see fig.1 and col.1, lines 50 - 66	1 & 11 at least
X	US 3127016	(BAIGENT) see whole document	1, 3, 9, 11 & 15

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		