A flute inspection apparatus comprising a laser distance sensor (44) arranged to inspect fluting of a corrugate, or a corrugated layer for forming a corrugated sheet (22), as it streams past the sensor (44) to read the approximate shape of flutes thereof as it passes the sensor (44) by taking an average of at least eight height readings along each flute's waveform. The laser distance sensor (44) will generally have a distance reading frequency capability in excess of 5kHz. Usually the corrugate or corrugated layer is inspected while curved around a roller (46). The sensor (44) can be arranged to direct its laser substantially radially with respect to the roller's central axis. The apparatus is generally mounted within a corrugator. There is also disclosed a method of fault detection in a corrugator using such an inspection apparatus wherein data from the at least one sensor (44) is analysed by at least one processor and a general shape or form of each flute is determined or evaluated or compared against a standard from the heights measured.
The present invention relates to a flute inspection apparatus and process for inspecting flutes, i.e. corrugations, within a corrugated sheet manufacturing line.

A corrugated sheet typically comprises a corrugated layer capped on one or both sides with a face sheet or backer liner, although the corrugated sheet can also be uncapped. A corrugated sheet can also comprise more than one corrugated layer. For example for a dual wall corrugated sheet there can be a top sheet, a corrugated layer, a middle backer liner, a further corrugated layer and then a bottom sheet. Additional or fewer layers can also be provided for further variants of corrugated sheet, and the liners, sheets or layers can be made of different thicknesses of material, or matching thicknesses of material, and the corrugations can either match or differ in their shape, amplitude or wavelength. As a result there are many different forms of corrugated sheet.

The corrugations within the corrugated layer(s) of a corrugated sheet serve an important structural influence on the properties the corrugate sheet, be that in calliper, bending strength, torsional strength, compressive strength and weight. For example, variations or irregularities in the corrugated form can greatly alter the strength of the finally assembled corrugated sheet, and that can compromise the integrity of a product made therefrom. It would be desirable, therefore, to provide a means for testing or inspecting the shape or form of the corrugated layer in a corrugated sheet, preferably across the width of the flutes, rather than just at the edges of the sheet.

The idea of inspecting a corrugated sheet, or a board made with a corrugated layer, for irregularities using an inspection apparatus is nothing new. US5581353, for example, discloses a laser based measurement apparatus and method for the measurement of multiple corrugated board characteristics, including calliper, or thickness, surface flatness and board flaws such as areas of delamination or crush, and it can do this within the production line of the board. It does so by pointing a laser beam at both sides of the assembled board, using a laser diode on each side of the board, and taking readings of the reflected light, and determining from the dual measurements the board's varying calliper (thickness). Irregularities can be determined as the board might
be thicker if there is a delamination, and it might be thinner if the core has been crushed.

US5581353 can also analyse readings from just a single surface to look at flute-ridge measurements, particularly the amplitude of the corrugations. As disclosed in US5581353, this approach can determine flute heights for each corrugation, perhaps at a frequency of between 500 and 1000 hertz, as the corrugated sheet or board passes the sensor. However, US5581353 cannot consider the shape of the flutes of the corrugated layer as the inspection is carried out on the assembled board, whereby the flutes are not directly visible.

Another approach for corrugated sheet inspection is disclosed in US8593649. This again is a quality control inspection, but rather than looking at the outer sheets, it now looks directly at the corrugated layer prior to it being capped, but by looking instead at reflected light characteristics from an angled light source. By angling the light source, variations in the ridge peak heights of a first flute will vary the location of a shadow cast thereby on a neighbouring flute. By inspecting the pattern of the reflected light, US8593649 suggests that it is possible to identify variances in the flute heights. Again this does not consider the shape of the flutes, and it cannot do so either as the majority of the flute is never able to be illuminated by the light source as a consequence of the required angle of the light source.

It would be desirable, therefore, to provide a device for inspecting the full shape of the flutes, or at least to provide a more complete picture of the flutes, for allowing the determination of a wider range of flaws in the form of the fluting, rather than just flute height variations.

According to the present invention there is provided a flute inspection apparatus comprising a laser distance sensor arranged to inspect fluting of a corrugate, or a corrugated layer for forming a corrugated sheet, to read the approximate shape of flutes thereof as it passes the sensor by taking an average of at least 8 height readings along each flute's waveform.
The present invention is preferably arranged for use within a high speed corrugator or assembly line, for example one that is capable of moving the corrugate, or corrugated layer, at speeds in excess of 200 meters per minute.

Preferably the flutes have a wavelength between 1mm and 20mm.

Preferably when the corrugator or assembly line is operating at production speeds, the flutes pass the sensor at a frequency of above 300Hz, and perhaps in excess of 1000, 2000 or even 3000Hz.

Preferably when the corrugator or assembly line is operating at production speeds, the flutes have a period as they pass the sensor of less than 10ms.

Typically the laser distance sensor will have a distance reading frequency in excess of 5kHz, but preferably the laser distance sensor has a distance reading frequency in excess of 10kHz and more preferably in excess of 20kHz. A sensor having a distance reading frequency capability between 10kHz and 50kHz is generally adequately fast for most commercial flute characteristics in the corrugated cardboard industry, and such sensors are available from Wengler, and other specialist laser sensor manufacturers. Custom sensors, with faster sensor frequencies, may be required where more detailed flute analysis is desired.

Preferably the sensor is arranged to direct its laser substantially perpendicular to the apex (i.e. the top or peak-height) of the flutes.

Preferably the sensor comprises a laser output and a reflected laser light receiver.

The laser output can be arranged to direct the laser substantially perpendicular to the direction of movement of the corrugate, e.g. when moving linearly, or substantially radially with respect to the roller when the corrugate is being inspected while curved around a roller such that when the corrugate is inspected while curved around a roller, the sensor is arranged to direct its laser substantially radially with respect to the roller's central axis.
It is preferred that the laser output is arranged to direct the laser substantially perpendicular to the flute at the point of intersection with the flute peaks, particularly when the flutes are intended to be symmetrical about the flute peak.

Preferably the laser distance sensor is arranged to have a point of detection for the corrugations on a radially external part of the corrugate pathway as it bends over a roller, or on an exposed surface as it is supported on a roller or belt.

By being on a roller or belt, the corrugate is supported, thus reducing flutter (which can cause reading irregularities). It is preferred for it to be supported on a roller, however, as while it is being flexed at that point, i.e. being bent around the roller, the flutes become slightly more open for inspection, and thus allowing a wider viewing angle for locating the laser distance sensor

By having the detection or inspection arranged at a brake roller within the corrugator or assembly line, the corrugate is also being tensioned, thus further minimising flute flutter. It is preferred, therefore, that the inspection or detection occurs as the corrugate is bent around a brake roller.

Preferably the corrugate or corrugated layer is inspected while curved around a brake roller within a corrugator or assembly line.

The brake roller is commonly located after a bridge in the corrugator or assembly line, but before a combiner unit of the corrugator or assembly line (where single faced corrugated webs are combined to form the double walled, tripple walled, or other form of, corrugate).

The inspection may alternatively, or additionally, occur elsewhere within the corrugator or assembly line, such as prior to the bridge - e.g., on for each single facer, located after the corrugated layer is faced with a first facing sheet, but before it gets to the bridge. Preferably it will be located shortly after the gluing step of that single facing step, and preferably at a roller thereafter. Preferably the single faced web is tensioned about that roller to reduce flutter.
The inspection of the single faced web can enable closed loop control of some of the controls on the single facer unit, for example to automatically correct errors seen in the single faced web.

As suggested above, it is preferred that the sensor is located as close as practical to where the single faced web exits from the single facer unit, although there may be some preferance for greater distances therefrom to enable the web to be put under tension and supported on a roll, while also encompassing appropriate needs for adhesive to have adequately set, and for allowing the sensor to be adequately protected from the environment of the facer unit, and downstream water sprays, i.e. protection from heat and moisture etc.

The sensors output distance data, representing the distance of the point of intersection of the laser with the flute. This data can be passed to a processor so that the processor can output calculation results indicative of the characteristics of the inspected flute.

Preferably distance data output by the sensors represent the distance of the point of intersection of the laser with the flute, and that data is passed to a processor so that the processor can output calculated results indicative of a characteristic of the inspected flute.

Preferably the data from the sensor is passed to a processor in batches. Preferably the batches are between 400 and 1500 sample points or samples at a time. More preferably the batch sizes are less than 1100 samples and more preferably the batch sizes are less than 600 samples at a time. By reducing the number of samples in a data batch, a smaller number of calculations are needed to be carried out on the batch, whereby the processor can more readily complete the necessary calculations before receiving the next batch of sample readings. This avoids discontinuities in the outputted calculation results.

It is generally impractical for a distance sensor to provide a continuous stream of individual readings to a processor, and batch outputs are the more common approach utilised by proprietary sensors, but the present inventors realised that costs can be reduced by reducing batch sizes, thus allowing less costly, or fewer, downstream processors to be used.
Preferably multiple laser distance sensors are provided across the width of the corrugate/corrugated layer (i.e. along the length of the flutes). It is preferred, therefore, that multiple laser distance sensors are provided to take readings in multiple locations along the length of the flutes.

The sensors may point horizontally, or at any other angle, but preferably they point generally downwards so that dust from the corrugator will not collect on the optics/laser. As will be appreciated, there can be a lot of dust within a corrugator, due particularly to the particulates coming off the material being processed - commonly a paper or fibrous material.

Preferably the sensors are spread across the width at an even distribution, such as at 10, 15 or 20 cm centres. More preferably the sensors are arranged to be more concentrated at the edge regions of the corrugate/corrugated layer since it tends to be at the edge regions where pinching occurs during the manufacturing process through an incorrect set-up of the pinch rollers, or feed rollers. For example, sensors may be spaced between 20 and 40 cm apart in the middle region of the width of the inspected sheet and between 10 and 20 cm apart across the outer regions. These regions may be defined as the width-wise inner and outer thirds of the sheet, each “third” extending longitudinally along the fed web. Another arrangement would be to have those regions respectively as the middle three-fifths and the outer one-fifths. The locations can also be customised for a particular corrugator or assembly line, e.g. where known set-up issues occur, such that the sensor numbers are more concentrated at those known problem areas.

Where the inspection is an inspection of a corrugated layer of a corrugated sheet, the laser distance sensor, or each laser distance sensor, is preferably provided in a location of the corrugator/assembly line after the layer’s attachment to a first facing sheet, but prior to application of a backer liner to the opposite side thereof, such that the flutes are attached to the first facing sheet to lock the relative wavelengths of the sequential flutes together, but while still having the flutes inspectable on the layer's other side.
Preferably at least 10, and more preferably at least sixteen, readings are taken per flute as the corrugate passes the laser distance sensor. Ideally between 30 and 50 readings per flute are taken. By taking more readings a more detailed picture of the shape of the flute can be determined.

Data from the sensors, whether taken before or after the bridge, could be fed into the corrugator process control system where the settings and production data for the flute type and board grade are stored and where edge delamination or centre delamination can be determined by processors. One use for this data can be for the control system to then use the data to automate adjustment of settings on the single facer to correct its operation in view of the sensed problem. Typically the adjustment on the single facer would be any one or more of pressure roll settings, corrugator roll pressures, glue gap settings or corrugator roll to glue roll gap settings.

By having this sensed before the bridge, the errors can be detected earlier.

By having this sensed after the bridge, the data would more likely be used to automate a rejection of the faulty board - it can be more readily discarded by the downstream processing units. This is preferred since calibration across the bridge is generally difficult as the bridge functions as a web buffer, allowing the single facer units, and the combiner unit all to operate at individual speeds when desired, thus not needing them to index closely together at all times.

Preferably the speed of the corrugate or corrugated layer past the laser distance sensor peaks at a speed that is between 200 and 500 metres per minute.

Typically the laser distance sensor is mounted between 20 and 50 mm from the expected peak height of the flutes.

Preferably the dot size of the laser on the flute has a diameter of between 0.1 and 1 mm. Most preferably it is about 0.5 mm.

Preferably the or each laser distance sensor is mounted on a part of the corrugator/assembly line that is generally subjected to no more than low magnitude
vibration. Preferably the mean magnitude (amplitude) of that vibration is no more than 0.4 mm. Vibration is undesirable, just as flute flutter is undesirable, as it can introduce measurement errors from the sensor(s).

The sensors may be mounted on a separate boom arm, opposite the roller, or on an existing frame of the machinery, where an appropriate frame already exists. As such it can be retrofitted to existing machinery if desired.

It is preferred that the present invention is retro-fitted to existing corrugators or assembly lines, and it may be provided for that purpose as a kit, comprising the sensor(s) on such a boom arm for assembly into the corrugator or assembly line.

The boom arm may have a cable for connecting the outputs to a processor, or the processor may be on the boom arm.

Preferably the boom arm has at least one cable extending therefrom for connecting the outputs of the sensors to at least one processor.

Alternatively the boom arm may have at least one cable therein for connecting the outputs of the sensors to at least one processor on or within the boom arm.

Each sensor may feed its data to its own processor, or sensors may be grouped for a particular processor, or there may be intermediate processors for groups of sensors, for sending fully or partially calculated data to a central processor. These processors may be on the boom arm or separate therefrom.

Preferably there is a processor for each sensor. The processors may be on the boom arm, or connected thereto by a wired connection. Data volumes are unlikely to be supportable by wireless connections, although where high enough data transfer rates are achievable, wireless connections could also be contemplated.

The processors may be mounted singly on processor boards, or together in groups on processor boards, such that a board may process data from a single sensor, or a cluster of sensors, or all of the sensors. For example, there may be a plurality of
processors, and more than one processor is grouped together in a group on a processor board such that the board may process data from more than one sensor.

The calculated data can be output from the processor(s) for presentation or onward use. For example, it may be presented by conventional display means to a user, such as by a light array, or a monitor, or by audible indications. The presented information may provide complex information, such as quantified or visually indicative variations from expectations, or it may simply indicate whether the data passes or fails expectations.

The data may instead, or additionally, be sent to an automated control processor of the corrugator or assembly line, for allowing control feedback of the corrugator or assembly line. This might facilitate automated adjustment or shut-down of equipment in the event of highlighted delamination from the top sheet or highlighted flute crush on the corrugated layer, or some other failure of the corrugation form, or even automated discard of offending product further down the assembly line process. Such actions can help to prevent unnecessary down-time of the equipment.

The present invention also provides a method of fault detection in a corrugator using an apparatus as defined above, wherein data from the sensor is analysed by a processor and the general shape of the flutes are determined from the heights measured.

The present invention also provides a method of fault detection in a corrugator using an apparatus as defined above, wherein data from the at least one sensor is analysed by at least one processor and a general shape or form of each flute is determined or evaluated or compared against a standard from the heights measured.

Preferably the method compares the detected heights against expected heights for the form of corrugate being inspected.

Preferably the method compares the detected heights against the mean-square of the flute heights, and a processor looks for results falling outside accepted parameters.

Preferably the method plots its results on a visual screen.
Preferably the method plots data relating to acceptability of the readings on a visual screen.

Preferably the plotted data from multiple sensors along a flute streams down or across a screen to create a heat map for the successive flutes of the corrugate or corrugated sheet.

Preferably the wave-form asymmetry of the flutes is analysed as the corrugations typically should be symmetrical. Asymmetrical characteristics can then be flagged when detected.

The method may analyse flute wavelength or consistency, for example by looking at how many flutes are sensed in a fixed time frame, or by looking at flute wavelengths per flute, or per x-number of flutes, to see if the values change, or whether average values change or whether rolling values change.

Another output from the signal processing transform can be a value proportional to the mean-square of the flute-height. The use of a mean-square better highlights variances as they become exaggerated.

These and other features of the present invention will now be described in greater detail with reference to the accompanying drawings in which:

Figure 1 shows a possible arrangement for a corrugator or assembly line for producing a double wall (or two wall) corrugated sheet - one having two corrugated layers;

Figure 2 shows a detail of the section of the corrugator or assembly line of Figure 1 where three components (a first corrugated layer with backer sheet, a second corrugated layer with backer sheet and a top face sheet) of the double wall corrugated sheet are combined to form the double wall corrugated sheet;

Figure 3 shows a further schematic of a possible corrugate’s feed pathway, in which a laser distance sensor is shown adjacent one of the rollers;
Figure 4 shows a schematic elevational view of a typical roller, with a possible sensor bar - a boom arm - applied adjacent thereto;

Figure 5 shows a possible boom arm arrangement, with schematic sensors and processor boards;

Figure 6 shows a perspective view of one end of the possible boom arm of Figure 5, with a possible leg structure and end for passage of cabling;

Figure 7 shows a further perspective view of a possible boom arm, like that of Figures 5 and 6, but from the other end thereof compared to Figure 6, and better showing a possible adjustable leg form - a bolt can be turned to adjust the slidable height of the boom arm by adjusting the length of the leg;

Figure 8 shows a sample trace of a shape of flutes of a corrugate using a low resolution detection; the shape is visible, but the detail is minimal;

Figure 9 shows a sample trace using a higher resolution sensor; the detail is better;

Figure 10 shows a sample trace using a higher speed passage past the sensor - fewer corrugations are seen in the same timeframe (x-axis), but the shape is still clear;

Figure 11 shows a sample trace using a sensor output from a high frequency sensor operating for half a second at 40000 samples per second (samples counted on x-axis) with distances recorded on y-axis - the sensor was located around 3.6cm from the peaks of the flutes. The testing was carried out on a brake roller so there is no discernible flutter;

Figure 12 shows a sample trace from a sensor showing four distinct defect regions and a degree of drift signifying corrugated sheet flutter - drift or vibration from its intended line; the large deflection related to an overlap in the test strip, as this is created on a test rig (a wheel), with the final blip being a repeat of the first blip, and the drift arises from an imperfect application of the strip of corrugate onto the wheel;
Figure 13 shows the sample trace for the sensor readings when discontinuities have been arising from the processors due to oversampling, i.e. sending the raw data from the sensors in overly large batches, thus resulting in calculation over-runs by the processor, and consequential missing data in the results stream;

Figure 14 shows a trace for the flute asymmetry analysis of the flute data, where variations above or below uniformity are reflected by readings above or below the 200% average;

Figure 15 shows a sample trace of flute height proportional to the mean-square of the flute height, rather than a pure flute-height trace; it greater highlights disparities from the norm, as can be seen by the two downward spikes towards the right of the trace (both representing crushed flutes - crushed for the purpose of the test); and

Figure 16 shows an example of a possible computer screen read-out for an operator, for highlighting flute damage, and its location on the corrugated sheet in the form of a heat map.

Referring first of all to Figure 1, there is shown a manufacturing line 10 for producing corrugated sheets 12.

The corrugated sheets 12 in this example are a double wall corrugated sheets. These can also be called twin wall or two wall sheets. The finished sheet comprises a top layer, a corrugated layer, a middle layer, a further corrugated layer and a bottom layer. As a consequence, stock paper is being fed from five separate rolls of stock paper. Five further rolls 16 are also provided at the upstream end of the manufacturing line 10 to allow quicker changes of stock paper as or when any of the first rolls are depleted. There are many possible variations for the production line, and these spare rolls may be located off line initially, and be only brought into the production line when needed.

Instead of paper, the sheet may be made of plastic.

Instead of a double wall, it could be a tri-wall, or a single wall corrugated sheet. It can even be a non-backed corrugate if the material used is self-supporting.
This disclosed arrangement for the manufacturing line, assembly line or corrugator is one of many standard manufacturing line designs that exist, and the specifics of the design are non-critical to the invention. As such, other known layouts for corrugators and assembly lines featuring corrugate, are also applicable, particularly those for single wall or tri-wall corrugates.

In the illustrated arrangement, two rolls 14 are combined as a back sheet and a corrugated sheet for carriage across a first bridge 198 and then an elevated further bridge 20 to a tensioner or brake 22 prior to then being combined at a combiner unit 24 with a similar back sheet and corrugated sheet combination, and also a further bottom sheet, for passage thereafter, in its combined multi-layer form to downstream processing units 26. These downstream processing units 26 may include creasing, cutting, scoring, printing or perforating units, or other typical downstream processing units known in the art. In this example, the finished and cut-out corrugated sheets 12 exit the downstream processing units as cut, scored and perforated individual blanks, with some passing to a first stacking unit 28 and others passing to a second stacking unit 30.

There can also be a reject bin 32, herein positioned amongst the downstream processing units 26, into which rejected sections of the corrugate can be cut from the web-stream and ejected. The reject bin may be elsewhere positioned, e.g. near the stacking units 28, 30, but by placing them more upstream, the rejected material can be rejected before it gets further processed by the downstream processing units 26.

As shown in the key 34, this manufacturing line 10 can be provided with a plurality of different sensors or actuators and other components. For example, there are wrap arms, temperature sensors, proximity sensors, water spray elements, glue gap checkers, bridge contents photocells, moisture sensors, bridge tension interfaces for applying a brake force for tensioning, pressure sensors, steam showers, web presence checkers using photocells as an example, traction providers, profile checking devices, all in addition to the laser distance sensor 44 of the present invention. These other components are standard in the art and will not be further discussed herein.

Referring now to Figure 2, a blown up portion of the manufacturing line 10 of Figure 1 is shown. This blown up view shows the further bridge 20 and its first backed
corrugate 42, a third bridge 40 for a second backed corrugate 38, a top face sheet 36 coming from a further roll 14 of stock paper, a brake 22 for each of these web-streams and a combiner unit 24, with feed rollers 33, a gluing unit 34 and a pinching unit 35.

As can be seen, in this embodiment the second backed corrugate (or second wall 38) is arranged between the top face sheet 36 (herein the bottom layer) and the first backed corrugate (the uppermost of the three layers to be combined).

This second wall 38 is carried over the third bridge 40 to its brake 22 in a corresponding fashion to the first wall 42.

The top face sheet 36 is also provided with a brake 22 so all three sheets are tensioned together.

The brakes 22 provide localised tension to the webs that form, respectively, the first wall, the second wall and the top face sheet 42, 38, 36. The tension occurs since each web, or the combined sheet, is pulled from a location downstream of the brakes. This might be by the feed rollers 33, or the pinch rollers 35, or by some other component of the manufacturing line.

In view of this tension, the webs tend to be relatively stable as they pass around the brake rollers 22. This is therefore a good location to mount a flute sensor of the present invention.

As shown in Figure 2, the flute sensors 44 (laser distance sensors) are mounted adjacent the brake rollers 22, but only in this example for the upper two brake rollers, i.e. for the first wall 42 and the second wall 38. A third is not needed in this instance for the third brake roller 22 as the web there is not corrugated.

The flute sensors are laser distance sensors and comprise a laser output for being directed towards the corrugated side of the first and second walls and a receiver for receiving the reflected light from the flutes/corrugations.

As shown in Figure 2, the flute sensors 44 are provided at the downstream end of the bridges 20, 40. However, it is more likely that there will be a larger space than that
shown between that downstream end of the bridges and the brake roller 22 (it is not drawn to scale) so a separate boom arm is more likely to be provided for carrying the sensor(s). This boom arm will be provided adjacent the brake roller 22 to allow the flute sensors 44 to be mounted close to the flutes, e.g. within 10-50mm therefrom, to ensure accurate distance readings, and thus accurate flute shape readings.

Usually the flute sensors are mounted within between 10 and 50 mm of the expected peak locations of the corrugations, although a distance of between 30 and 40mm is preferred.

Although this manufacturing line 10 is shown to be for making a twin or double wall corrugated sheet, if only a single wall and top face was to be provided, that would then be a single wall corrugated sheet and only a single sensor bar would be needed as only one corrugated web would be present. Likewise, if a further web was to be provided for a third wall, then a tri wall corrugated sheet would be being produced, and appropriate tables and fees rollers etc. would be provided for that, and thus three sensor bars would be provided - it is preferred that each corrugated layer is inspected as a fault in any of them can compromise the final product.

It is therefore preferred that at least one flute sensor is provided for each "wall" of the corrugated sheets 12. A flute sensor is not needed, however, for the "top face" stream, as that layer is not corrugated.

Referring now to Figure 3, a schematic of a possible alternative arrangement for the provision of the flute sensors is provided. In this example, the flute sensors are provided on a roller located downstream of the brake roller 22. This might be needed if the preferred brake roller location is unsuitable due to the structure of the assembly line, or the orientation of the web at the brake roller.

Another possible arrangement would put the sensors on an upstream roller 48, rather than the downstream roller 46.

The sensor 44 could also be located elsewhere within the manufacturing line, prior to application of the top face sheet to the single faced corrugate of the first wall (or the second wall, or even the third or subsequent wall where provided). It is important,
however, that the flute has an uncovered side to allow it to be inspected. This also has
the effect of ensuring that it remains flexible enough to bend around a roller - the
preferred detection location. It is to be appreciated, however, that the flutes could
instead be inspected while the sheet is flat, rather than curved around a roller, e.g. on a
support bed, if provided. The support is helpful as it reduces flutter (and thus reduces
interference).

It is preferred to locate the flute sensors close to the brake 22, however, since that is the
location where flutter is reduced to an acceptable level - there is less sheet vibration interference in the inspection readings.

As shown in Figure 3, the roller 46 downstream of the brake roller 22 is preferred in
that instance to the brake roller 22 since the corrugated layer of the single faced web is
on the external side of the downstream roller 46, whereas it is concealed against the
brake roller 22. More conventionally, however, the brake roller 22 will be provided to
receive the corrugate or web with its corrugations on the radially external side thereof,
thus allowing their detection and inspection at the brake roller 22. After all, with the
brake roller 22 directly engaging with the bottom face sheet of the corrugated web,
rather than the corrugated layer itself, this minimises the risk of flute damage as a
consequence of the operation of the brake roller 22.

It is also preferred that the flute sensors 44 are located downstream of the bridge since
damage may occur to the corrugations on the bridge as the bridge is provided to
receive slack within the web, whereby there is a risk of adverse folding of the single
faced sheet thereon.

A bridge is an important part of the manufacturing line in most corrugators since it is
difficult to control the relative speeds of the downstream processing units relative to the
single facing units provided upstream of the bridge. The bridge thus offers an area of slack to allow a less strict control therebetween.

Referring next to Figure 4, a schematic example of a possible boom arm for mounting
the flute sensors 44 is shown. This boom arm 50 is mounted at its ends 52 to a frame
54 on which the brake roller 22 is itself mounted at its ends 56. The boom arm 50 can
be provided with stays 58 to reduce vibration of the boom arm 50. As shown, these
stays terminate at the third nodes of the boom arm. They may alternatively both terminate towards the middle of the boom arm, i.e. at the central or half node, or elsewhere along the boom arm.

The boom arm 50 is preferably mounted about 35mm from the surface of the brake roller 22.

Referring next to Figure 5, an illustration of a proposed internal layout for a boom arm 55 is provided. As can be seen, this boom arm 50 has mounted thereon a plurality of laser distance sensors, i.e. flute sensors 44, each having a laser output 60 and a corresponding return path for the reflected light (both shown schematically). Figures 6 and 7 more clearly show these schematic representations of the laser output and return paths. In practice, however, they are likely to be non-parallel, and closer aligned, with the contact spot on the flutes having perhaps only a 0.1 to 0.5mm diameter, rather than the illustrated wide spread.

The boom arm 50 is mounted onto the frame via adjustable brackets or legs 64. This allows the distance between the boom arm and the roller to be adjusted without having to adjust the roller. It may be possible, however, for the roller to be adjusted relative to the boom arm instead, although that is probably more troublesome.

The inside of the boom arm can be seen to contain the equidistance spacing between the numerous sensors 44. Further processor boards are provided for mounting processors within the boom arm. The processors can process the data streaming from the sensors, usually in batches. As per Figure 5, there can be numerous processor boards, and there can be fewer processor boards than sensors. The numbers, however, could instead match.

As best seen in Figure 7, the legs are shown to be adjustable by a slidable connection, controlled by a bolt. Other mechanisms for leg adjustment are also possible, as will be understood by a skilled person.

Figure 7 also shows a hole in the connector between the leg and the box of the boom arm. This can allow cables from within the boom arm, e.g. for power to and data from the processors (or to and from the sensors if the processors are located away from the
boom arm - thus allowing a smaller boom arm) to connect with external processors or control/display units.

Referring next to Figure 8 through 14, the operations and use of the flute sensors, or more particularly the data therefrom, will now be described in more detail.

The purpose of the flute sensors is to inspect the flute. It is not simply looking at the height (amplitude) of the flute, but is inspecting the shape (wave-form) of the flute. As a consequence, the present invention is designed to help identify any visually detectable damage to the flutes, which damage may arise for example from an unintended compression or unintended delamination of the fluting relative to the backer sheet. Such faults will be manifested as irregularities in the waveform of the flute.

The flute sensor 44 enables a user, or more typically a processor as this is best done substantially in real time, to look at the shape of the flute, or to detect irregularities in that shape, and to reactor forewarn accordingly.

As can be seen from comparing Figures 8, 9, 10 and 11, different web speeds, different detection frequencies and different detection resolutions can offer different degrees of accuracy in the plots of the flute shape. Figure 8, for example, shows a low resolution distance sensor trace, albeit one where the existence of the corrugations are confirmed from top to bottom and along the sides of the waveforms. This is a crude implementation of the present invention as it does allow the detection of failed corrugations or missing corrugations. However, the capability of the sensor limits the effectiveness of the detection to low web speeds. The web speeds involved in this sample was 16 meters per minute, and the time-frame was 100ms (10x 10ms), and the frequency of detection was around 500Hz. Figure 9, on the other hand offers cleaner distance readings due to using a higher resolution, and faster, detector. Additional flutes are noted as well, despite the shorter time-frame (25ms - 10x 2.5ms) as the web speed was increased to 300 meters per minute. Sensor frequency here was around 10kHz. Figure 10 then shows a further trace, using the same equipment as in Figure 9, but at a web feed speed of 530 meters per minute. The time-frame of the trace illustrated in Figure 10 is only 5ms (10x 500μS).
Figure 11 then shows a final trace, over a half second period on a different flute profile, using a high resolution sensor at a sample rate of 40kHz. The trace very clearly shows the shape of the flutes, with little interference, although the x-axis is not representative of flute length, so the flutes are not shown to scale (likewise in the other figures). The web speed in this test was around 30 meters per minute.

Taking the readings and analysing them against expected readings for the waveform of the particular style of fluting being used requires a further processing of this data - the illustrations of the flute form are useful for detection integrity checking, but do not offer a viable quality control data stream as the stream comes through too rapidly. The present invention therefore also provides processing of this data against expected data.

As an example, a key to making comparisons on the flute distance signal is knowing the period of the flute pitch in the signal. This period will of course vary widely with web speed and flute type. Knowing this period is invaluable in knowing when to expect peaks, troughs, slope gradients etc., especially when trying to get close to 100% accuracy on flute counts etc. Knowing the intended shape is also important for this. Not having to rely on external speed encoders to get this information is an additional benefit. Instead, information about the flute type is instead able to be stored in a memory, thus allowing direct comparisons against sensed data, once the location within the waveform of the sensed data is calculated.

It is also to be observed that ascertaining this period directly from the sensor data is not always as straightforward as it sounds if the board is fluttering; the signal-to-noise ratio of the signal can create detection errors. Mathematical functions can thus be implemented with the signal processor to accurately recover the periodicity in the signal, the main periodic component being the flute.

Referring to Figure 12, a degree of flutter or machine irregularity is simulated by the test rig, by gluing a single faced board to a wheel, flute exposed, in the lab and then rotating it at speeds of around 300m/min to be representative of factory conditions. The sensed data from a complete cycle is shown, with the final bump being a repeat of the first bump. The small oscillations represent the corrugations, whereas the blips represent irregularities, with the large blip representing where the two ends of the
board overlap. There is also a radial variance in the trace from the rotation of the wheel as the board was not attached to the wheel in a perfectly smooth manner.

Referring then to Figure 13, the same test rig is used, but now the sample trace for the sensor readings has discontinuities which have arisen from the processors due to oversampling, i.e. sending the raw data from the sensors in overly large batches, thus resulting in calculation over-runs by the processor, and consequential missing data in the results stream. The results in Fig 12 did not have the discontinuities as the data was sent in smaller samples, and thus the processor completed any necessary calculations before the next block of data was received.

Wave-form asymmetry can also be analysed as the corrugations typically should be symmetrical. Asymmetrical characteristics can be flagged accordingly when detected. Figure 14 shows a chart representing wave asymmetry. It is displayed as flute peak-to-peak, divided by peak-to-trough, \( x \times 100\% \). So 200\% reflects 50:50 symmetry.

Flute wavelength or consistency can also be analysed, for example by looking at how many flutes are sensed in a fixed time frame, or by looking at flute wavelengths per flute, or per x-number of flutes, to see if the values change, or whether average values change or whether rolling values change.

Another output from the signal processing transform can be a value proportional to the mean-square of the flute-height. See, for example, Figure 15, which covers a 30-second period, and two crushes are clearly visible. The use of a mean-square better highlights variances as they become exaggerated.

Finally, regarding Figure 16, a proposed visual display summarising the flute inspection results is shown. The visual representation comprises an array of coloured indicators. The majority in this illustrated example represent no perceived damage or fault to the flute and are represented by a string of vertical columns each representing the positive readings of one of the sensors along the boom arm. As shown there are twenty five sensor readings, each having a vertical stream, and the leftmost stream through to the fourteenth leftmost stream all signify good fluting (the positive reading) and in a preferred screen arrangement these would be represented by green indicators. From the fifteenth column, however, it can be seen towards the lower end of that stream that
a fault is being detected as the colour is different - in preferred arrangements it will be
orange or red. However, as further time has passed, the fault has been corrected,
whereby the new lines inserted on the top row, pushing down the preceding lines, are
still green. As this continues, the indicator stream moves downwards.

In an alternative arrangement the stream may move sideways rather than vertically.

It can be seen that for the fifteenth column, no fault has been detected subsequent to
the now corrected error at the bottom. That error also was perceived not to be too
significant and thus in this example the error was signified by an orange indicator.
Then in the sixteenth column the error was detected more recently so the orange
indicators extend a little bit higher up the column, and so it continues.

As a consequence of the historical record being retained on the screen, at least
temporarily while the next sensed readings are presented, a pattern of problems can
become represented on the screen, and in this case this is illustrated as a streak
diagonally across the visual display, all in orange signifying the tail end of the detected
flaw, with the bottom right corner area, which in this example is coloured red on the
screen, signifying an unacceptable flaw. The problem may have been identified and
corrected, whereby it is now showing green across the full width, and the identification
may have been a warning to an operator or an automated trigger for corrective
feedback in the machinery, but either way the error is no longer happening, so a
correction or alteration in the machinery may have been made to fix the problem (which
in this instance may have been a delamination).

As the fault has been corrected, the topmost two rows are both signifying green again.

As a result of the detection, downstream of the sensor the section of the corrugated
sheets containing the flaw can also be traced or tracked, and then extracted from the
product line as discards, either automatically or manually.

The sensitivity of this equipment can also be modified by changing the rejection
sensitivities, or error parameters. The columns or tables in the right of this figure
signify the current settings, and a user can change these if desired via a control unit, or
computer input device. The flute types can also be entered so that the data used by the
look-up table of the fault detection circuitry or processor can be the correct data. In this example, the flute is a type C flute with paperweight of 85g.

The visual effect of this chart is similar to the opening sequence in the film The Matrix whereby the indicators track down the screen. This is the preferred way of indicating problems since it is usually striking and effective. Other ways of indicating problems may instead be used, including methods that do not utilise a visual output. For example they may include an alarm or simply an automated control system or rejection sequence down the line.

The present invention has therefore been described above purely by way of example. Modifications in detail may be made to the invention within the scope of the claims appended hereto.
CLAIMS:

1. A flute inspection apparatus comprising a laser distance sensor arranged to inspect fluting of a corrugate, or a corrugated layer for forming a corrugated sheet, to read the approximate shape of flutes thereof as it passes the sensor by taking an average of at least 8 height readings along each flute's waveform.

2. A flute inspection apparatus according to claim 1, arranged within a corrugator or assembly line.

3. A flute inspection apparatus according to any one of the preceding claims, wherein the flutes on the corrugate or corrugated layer have a wavelength between 1mm and 20mm.

4. A flute inspection apparatus according to any one of the preceding claims, wherein the laser distance sensor has a distance reading frequency capability in excess of 5kHz.

5. A flute inspection apparatus according to any one of the preceding claims, wherein the laser distance sensor has a distance reading frequency capability in excess of 10kHz.

6. A flute inspection apparatus according to any one of the preceding claims, wherein the laser distance sensor has a distance reading frequency capability in excess of 20kHz.

7. A flute inspection apparatus according to any one of claims 1 to 4, wherein the sensor has a distance reading frequency capability between 10kHz and 50kHz.

8. A flute inspection apparatus according to any one of the preceding claims, wherein the sensor comprises a laser output and a reflected laser light receiver.

9. A flute inspection apparatus according to any one of the preceding claims, wherein the sensor is arranged to direct its laser substantially perpendicular to the apex of the flutes.
10. A flute inspection apparatus according to any one of the preceding claims, wherein the corrugate or corrugated layer is inspected while curved around a roller, the sensor being arranged to direct its laser substantially radially with respect to the roller's central axis.

11. A flute inspection apparatus according to any one of the preceding claims, wherein the corrugate or corrugated layer is inspected while curved around a brake roller within a corrugator or assembly line.

12. A flute inspection apparatus according to any one of the preceding claims, wherein distance data output by the sensors represent the distance of the point of intersection of the laser with the flute, and that data is passed to a processor so that the processor can output calculated results indicative of a characteristic of the inspected flute.

13. A flute inspection apparatus according to any one of the preceding claims, wherein data from the sensor is passed to a processor in batches.

14. The apparatus of claim 13, wherein the batches represent between 400 and 1500 sample points.

15. The apparatus of claim 13, wherein the batch size is less than 1100 samples.

16. The apparatus of claim 13, wherein the batch size is less than 600 samples.

17. A flute inspection apparatus according to any one of the preceding claims, wherein multiple laser distance sensors are provided to take readings in multiple locations along the length of the flutes.

18. A flute inspection apparatus according to claim 17, wherein the sensors are spread at an even distribution, such as at 10, 15 or 20 cm centres.
19. A flute inspection apparatus according to claim 17, wherein the sensors are arranged to be more concentrated at edge regions of the corrugate/corrugated layer than in a middle region of the corrugate/corrugated layer.

20. A flute inspection apparatus according to any one of the preceding claims, wherein the inspection is an inspection of a corrugated layer of a corrugated sheet, the laser distance sensor, or each laser distance sensor, being provided in a location of the corrugator/assembly line after the layer's attachment to a first facing sheet, but prior to application of a backer liner to the opposite side thereof, such that the flutes are attached to the first facing sheet to lock the relative wavelengths of the sequential flutes together, but while still having the flutes inspectable on the layer's other side.

21. A flute inspection apparatus according to any one of the preceding claims, wherein at least 10, and more preferably at least sixteen, readings are taken per flute as the corrugate passes the laser distance sensor.

22. A flute inspection apparatus according to any one of the preceding claims, wherein at least between 30 and 50 readings per flute are taken.

23. A flute inspection apparatus according to any one of the preceding claims, wherein the speed of the corrugate or corrugated layer past the laser distance sensor peaks at a speed that is between 200 and 500 metres per minute.

24. A flute inspection apparatus according to any one of the preceding claims, wherein the laser distance sensor is mounted between 20 and 50 mm from the expected peak height of the flutes.

25. A flute inspection apparatus according to any one of the preceding claims, wherein a dot size of the laser on the flute has a diameter of between 0.1 and 1 mm.

26. The apparatus of claim 25, wherein the dot size has a diameter of about 0.5 mm.
27. A flute inspection apparatus according to any one of the preceding claims, wherein the apparatus is retro-fitted to an existing corrugator or assembly line.

28. A flute inspection apparatus according to any one of the preceding claims, wherein the sensors are mounted on a boom arm.

29. The apparatus of claim 28, wherein the boom arm has at least one cable extending therefrom for connecting the outputs of the sensors to at least one processor.

30. The apparatus of claim 28, wherein the boom arm has at least one cable therein for connecting the outputs of the sensors to at least one processor on or within the boom arm.

31. A flute inspection apparatus according to any one of the preceding claims, wherein each sensor feeds its data to its own processor.

32. A flute inspection apparatus according to any one of claims 1 to 30, wherein there are multiple sensors, and more than one sensor is grouped for a particular processor.

33. A flute inspection apparatus according to any one of the preceding claims, wherein there are a plurality of processors, each mounted singly on a processor board.

34. A flute inspection apparatus according to any one of claims 1 to 32, wherein there are a plurality of processors, and more than one processor is grouped together in a group on a processor board such that the board may process data from more than one sensor.

35. A flute inspection apparatus substantially as hereinbefore described with reference to any one or more of the accompanying drawings.

36. A corrugator comprising a flute inspection apparatus according to any one of the preceding claims.
37. A method of fault detection in a corrugator according to claim 36, wherein data from the at least one sensor is analysed by at least one processor and a general shape or form of each flute is determined or evaluated or compared against a standard from the heights measured.

38. The method of claim 37, wherein the corrugate or corrugated layer is moved past the sensor at speeds in excess of 200 meters per minute.

39. The method of claim 37 or claim 38, wherein when the corrugator is operating at peak production speeds, the flutes pass the sensor at a frequency of above 300Hz.

40. The method of claim 37 or claim 38, wherein when the corrugator is operating at peak production speeds, the flutes pass the sensor at a frequency in excess of 1000Hz.

41. The method of claim 37 or claim 38, wherein when the corrugator is operating at peak production speeds, the flutes pass the sensor at a frequency in excess of 2000Hz.

42. The method of claim 37 or claim 38, wherein when the corrugator is operating at peak production speeds, the flutes pass the sensor at a frequency in excess of 3000Hz.

43. The method of any one of claims 37 to 42, wherein when the corrugator or assembly line is operating at peak production speeds, the flutes have a period as they pass the sensor of less than 10ms.

44. The method of any one of claims 37 to 43, wherein data from the sensors is passed to at least one processor and calculated data is output from the at least one processor for presentation or onward use.

45. The method of claim 44, wherein the output calculated data is presented by conventional display means to a user, such as by a light array, or a monitor, or by audible indications.
46. The method of claim 44 or claim 45, wherein the output calculated data is sent to an automated control processor of the corrugator for allowing control feedback of the corrugator.

5 47. The method of any one of claims 37 to 46, wherein the method compares the detected heights against expected heights for the form of corrugate or corrugated layer being inspected.

10 48. The method of any one of claims 37 to 47, wherein the method compares the detected heights against a mean-square of the flute heights, and a processor looks for results falling outside accepted parameters.

15 49. The method of any one of claims 37 to 48, wherein the method plots its results on a visual screen.

20 50. The method of any one of claims 37 to 49, wherein the method plots data relating to acceptability of the readings on a visual screen.

25 51. The method of any one of claims 49 or 50, wherein the plotted data is from multiple sensors along a flute, and the plotted data streams down or across a screen to create a heat map for the successive flutes of the corrugate or corrugated sheet.

30 52. The method of any one of claims 37 to 51, wherein wave-form asymmetry of the flutes is analysed.

35 53. The method of any one of claims 37 to 52, wherein the method analyses flute wavelength or consistency.
Fig. 12

Fig. 13
### INTERNATIONAL SEARCH REPORT

**International application No**

PCT/GB2016/051830

#### A. CLASSIFICATION OF SUBJECT MATTER

<table>
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### Date of the actual completion of the international search

12 September 2016

### Date of mailing of the international search report

23/09/2016

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