

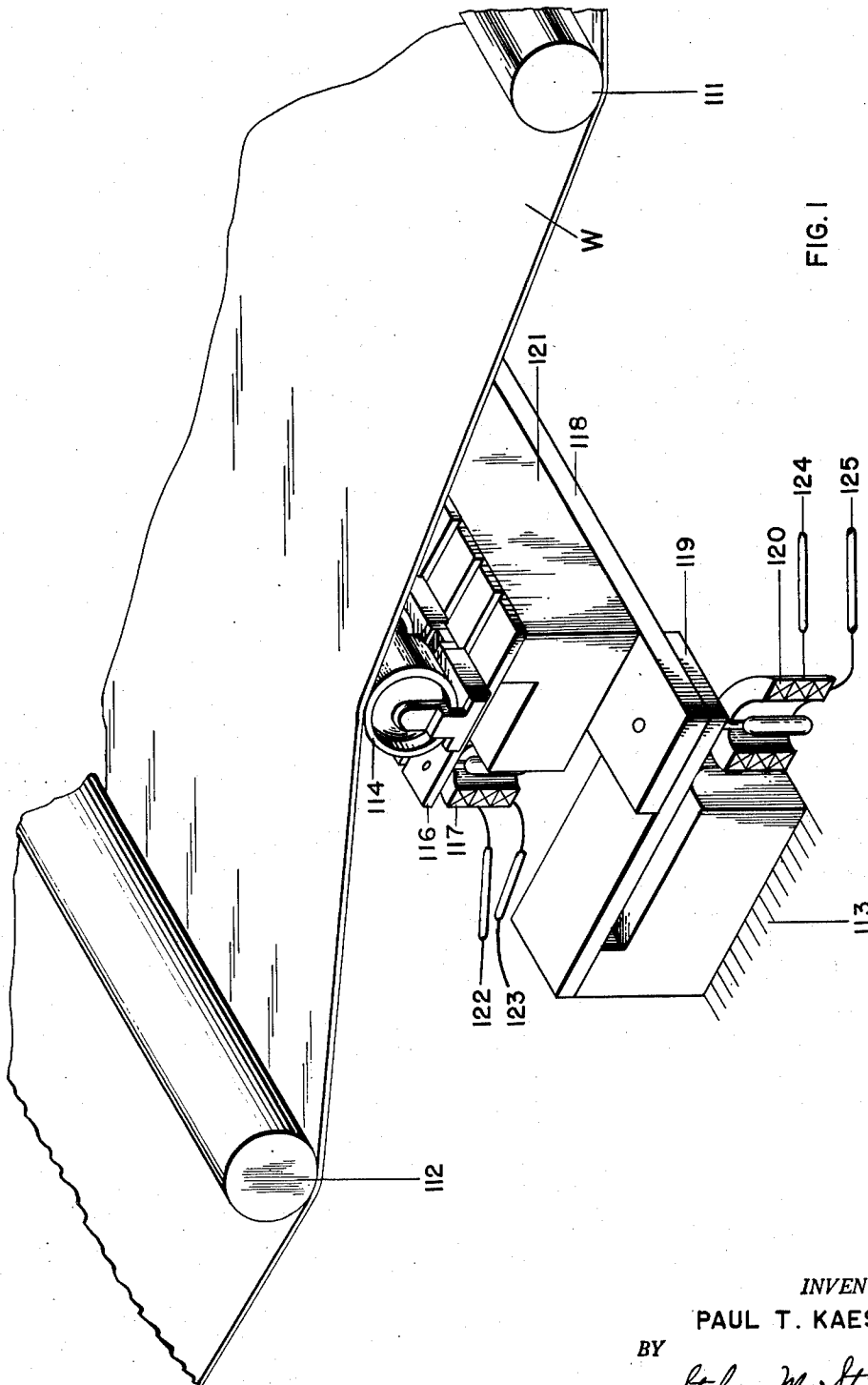
Oct. 15, 1957

P. T. KAESTNER
WEB FLATNESS INDICATOR

2,809,519

Filed Sept. 22, 1954

6 Sheets-Sheet 1



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6 Sheets-Sheet 2

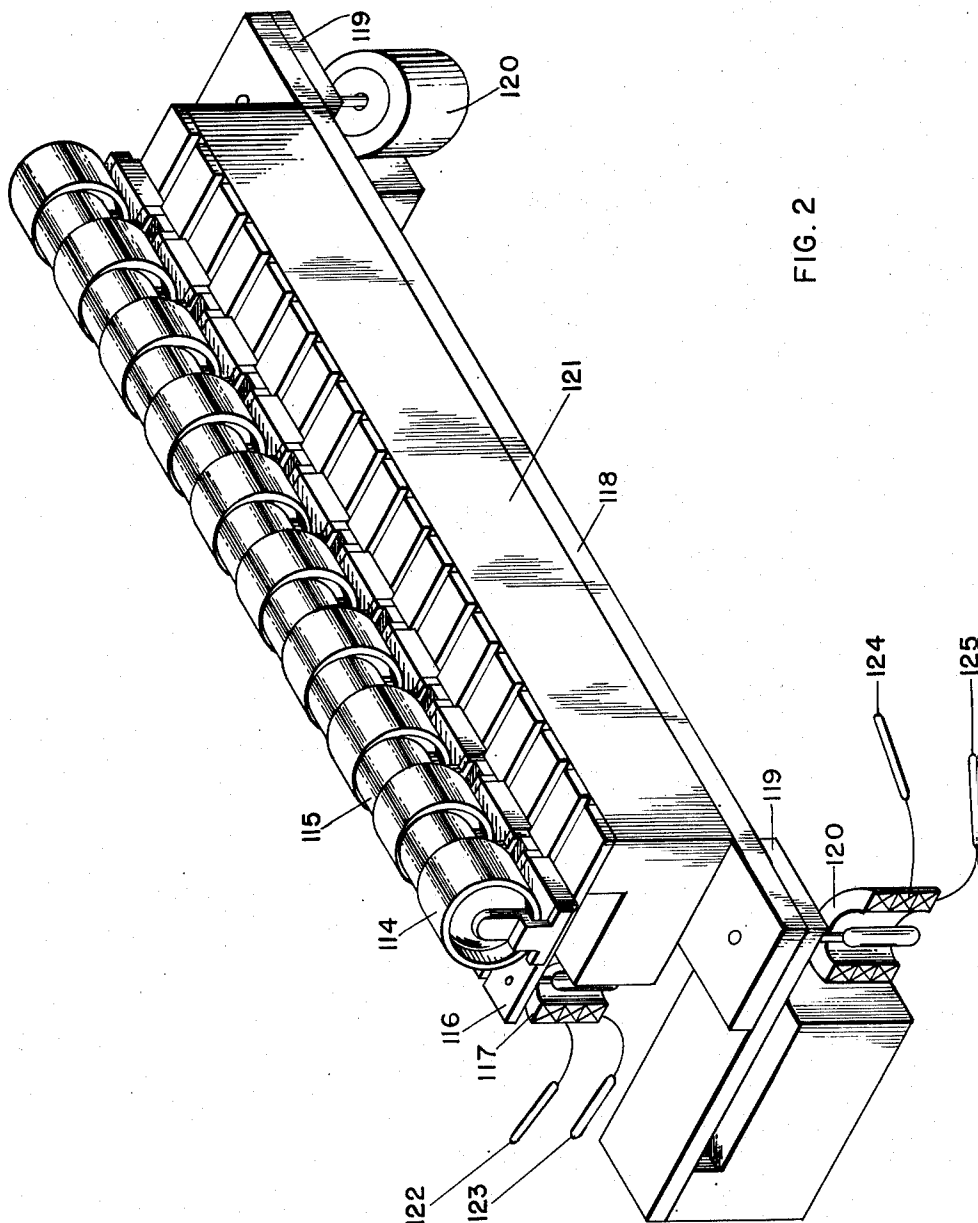


FIG. 2

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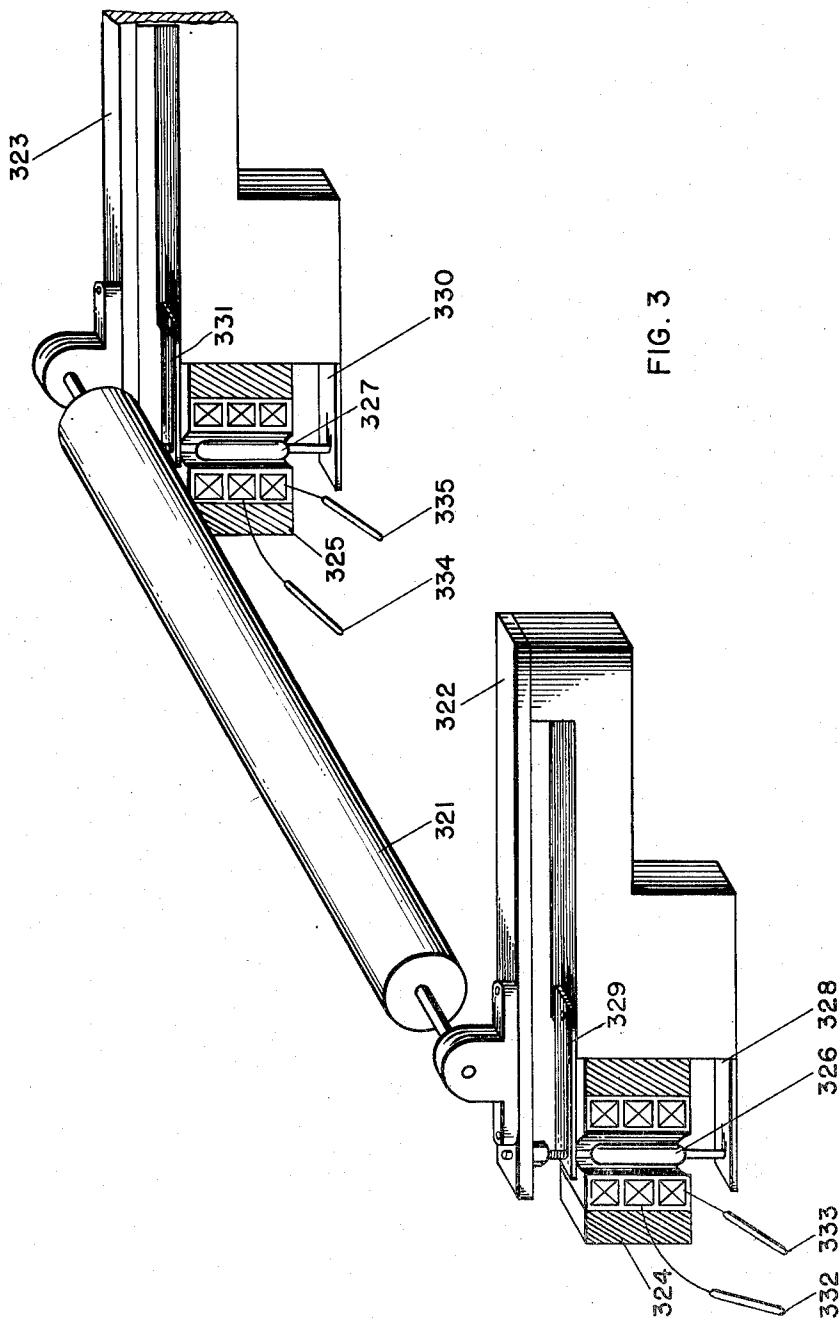
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6 Sheets-Sheet 3



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WEB FLATNESS INDICATOR

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6 Sheets-Sheet 4

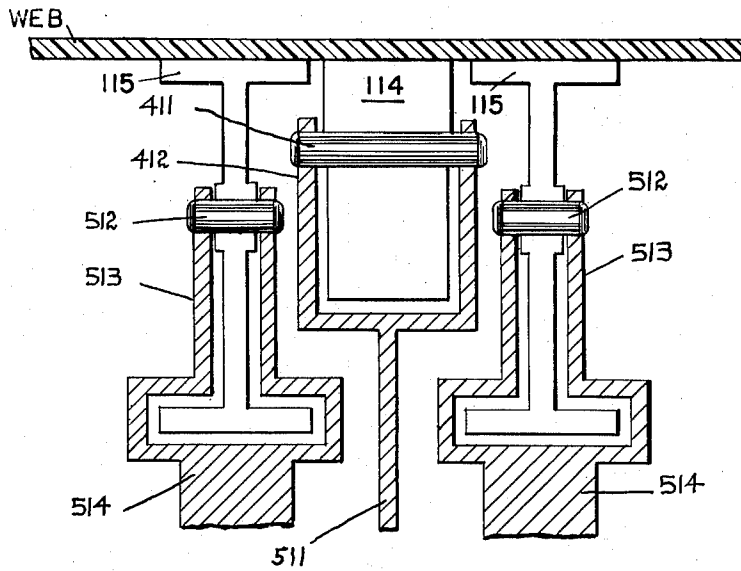


FIG. 5

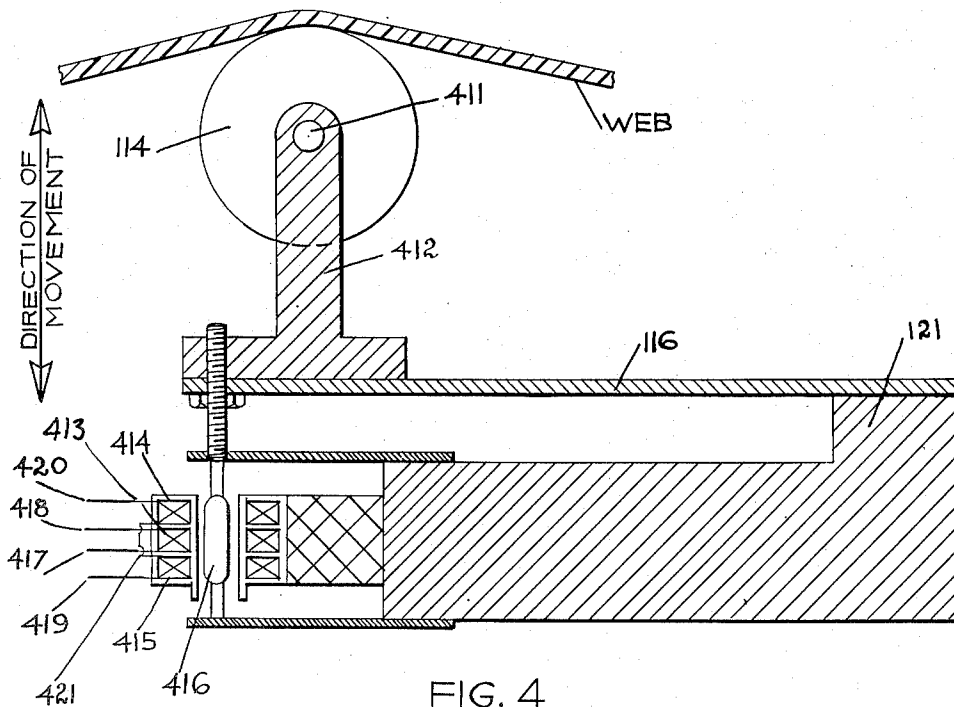


FIG. 4

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6 Sheets-Sheet 5

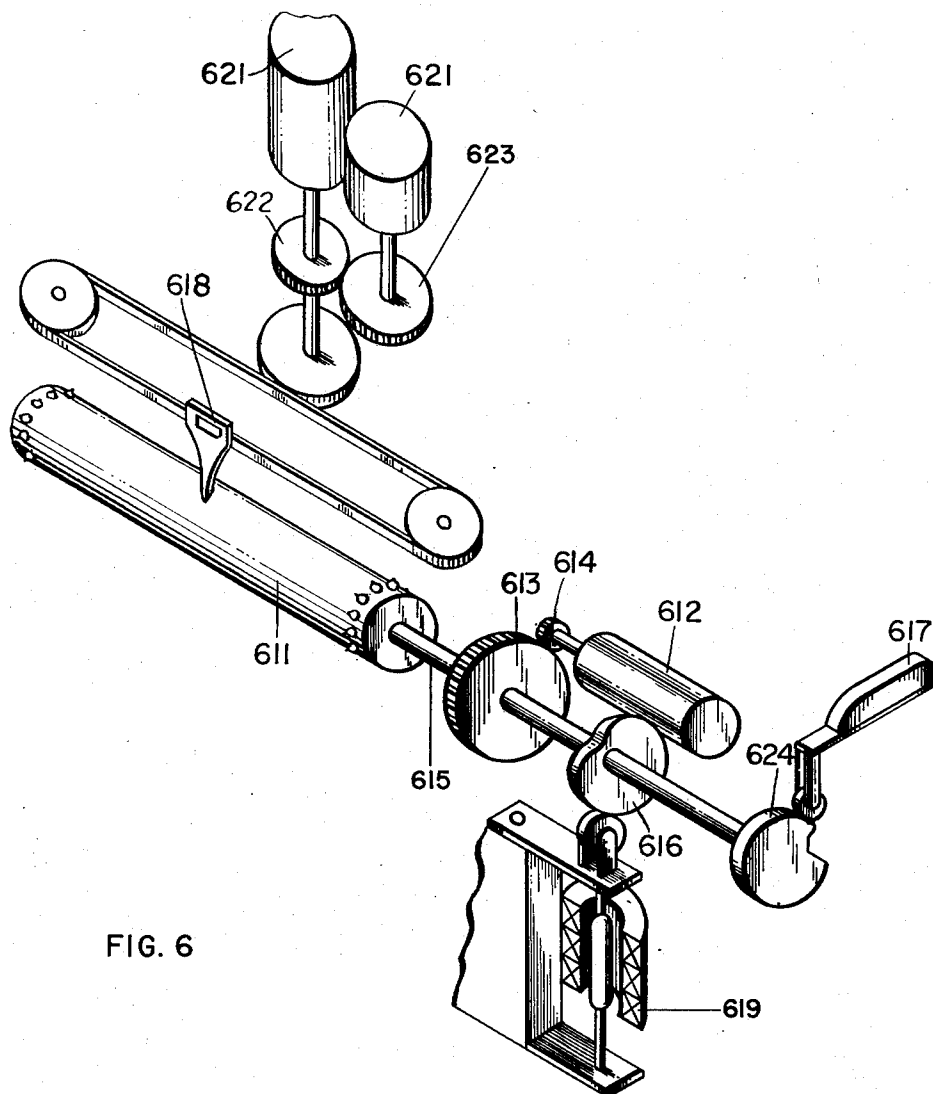


FIG. 6

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WEB FLATNESS INDICATOR

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6 Sheets-Sheet 6

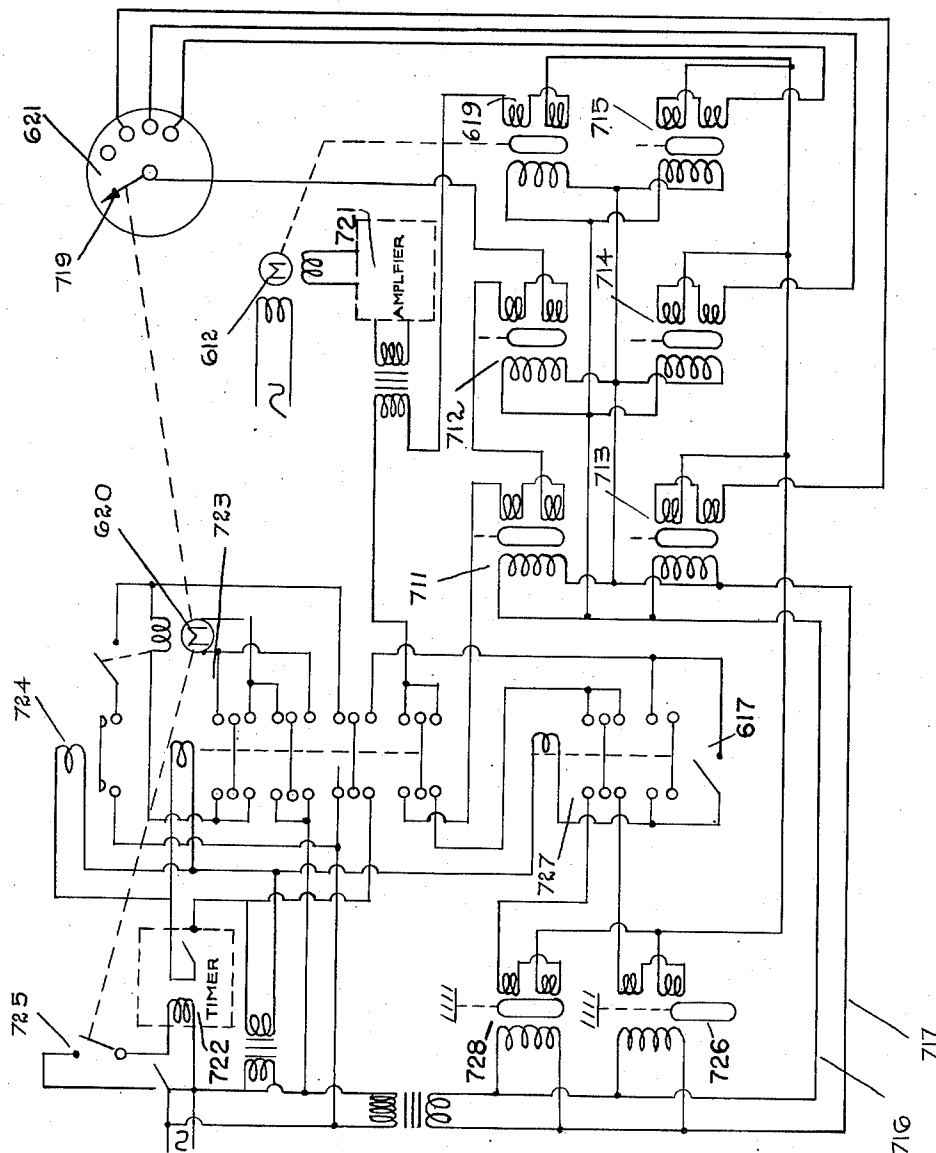


FIG. 7

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2,809,519

WEB FLATNESS INDICATOR

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Application September 22, 1954, Serial No. 457,655

4 Claims. (Cl. 73—159)

This invention relates to web measurement and more particularly to the measurement of individual lane lengths of a web and the use therefor.

In the various treatments and uses of webs it has been found that a detailed analysis of the web's various characteristics is frequently necessary. One characteristic of particular importance is "sheet flatness." This term is used to indicate the tendency of a web to sag more in some sections than in others when it is suspended across two parallel supports. For example, considerable difficulty in operation of converter equipment, such as printing and packaging machines using plastic web materials, is encountered if a web having a poor sheet flatness is used therein. In slitting operations, such as encountered in the manufacture of rolls of cellophane wrapping tissue or cellophane tape, lack of sheet flatness indication of the web causes much wastage since proper slitting cannot be performed to produce smaller rolls of satisfactory characteristics.

It has been previously found that a sheet flatness indication of a web can be obtained by measuring the length and/or the tension of individual longitudinal lanes of the web. An example of a prior art method is the "pull-out" test. This test is so called because it involved the measuring of the "pull" or displacement from the horizontal plane of longitudinal lanes of material as the material is hung at low tension over two supports such as two horizontal rolls. This method is limited in use because of its requirement for periodic sampling and poor correlation with the flatness of the material after slitting. Furthermore, the "necking down" or reduction of width of the web suspended between two supports at the center, especially in plastic webs as well as the transverse tensions that generally exist in webs are believed to indicate the importance of providing for measurement of sheet flatness as the web is being produced or used without the need for a sampling technique.

An object of this invention is an improved means for continuously determining, recording and utilizing certain characteristics of a web. A further object of this invention is an improved means for continuously determining, recording and utilizing certain characteristics of a web which is readily adaptable to existing web producing or handling machinery. A still further object of this invention is an improved means for continuously determining, recording and utilizing individual lane tensions existing in a web as well as the overall tension existing in the web as it is being handled in machinery.

It has now been found that in accordance with the objects enumerated above, sheet flatness of a web can be accurately determined by measuring the tensions existing in individual lanes by a series of individual lane tension responsive feelers while giving support to adjacent lanes, by measuring the tension existing upon the entire web with an overall web tension responsive feeler and coordinating such measurements upon a network circuit which automatically records the desired values. These

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records if desired may be used for directly or indirectly controlling the apparatus and process used in the making or in the use of the web. More particularly, it has been found that a truer determination, recordation and utilization of the sheet flatness of a web may be made by the use of individual lane tension feelers interspaced with supporting rolls spread laterally across the web which cooperates with an overall web tension feeler by a network circuit which produces signals substantially proportional to the true individual lane lengths. The indications produced by such signals for a series of stations or lanes transverse to the longitudinal lane of the film, produces a true picture of the sheet flatness. And if the apparatus is used for utilizing these signals for control purposes, one can effect a most economical process for making or using said webs.

The invention can be more aptly described by reference to the accompanying drawing in which:

Figure 1 is a view of a web being measured for its flatness by the flatness measuring device of this invention,

Figure 2 is a detailed view of an embodiment of a sheet flatness measuring device that may be used in this invention,

Figure 3 is a detailed view of an embodiment of an overall tension measuring device that may be used in this invention,

Figure 4 is a detailed side view of an embodiment of a web contacting or sensing element which may be used in this invention,

Figure 5 is a detailed vertical cross sectional view of an embodiment of one sensing and two supporting rollers that may be used in this invention,

Figure 6 is a pictorial view of an embodiment of a recording device that may be used in this invention, and

Figure 7 is a circuit diagram of an embodiment of an electrical network circuit which may be used in this invention for the purposes of directly recording individual lane lengths.

In Figure 1 the web W is shown being passed over two rollers 111 and 112. In contact with and displacing this web W from its line of travel is the sheet flatness measuring device of this invention attached to support 113. It consists of web feeler elements 114, each interspaced with supporter elements 115 closely spaced across the width of the web. Each of these elements is mounted upon spring biasing means 116 attached to support 121. The spring biasing means of the feeler elements 114 are connected to differential transformers 117 for the purpose of generating signals substantially proportional to the lane tension existing in each lane in the film. The supporting elements 115, interspaced between each of the feeler elements are used for the purpose of supporting the web between the lanes being measured thus minimizing the effects of adjacent lanes upon the lane being measured for tension. The entire series of individual lane tension measuring and supporting means are mounted upon a support 118 which in turn is mounted at its ends upon spring biasing means 119. These latter spring biasing means are each connected to a differential transformer 120. Hence, movement of the support 118 by the sum of the forces acting upon the individual lane tension feeler devices 114 and supporting elements 115 activates the differential transformers 120 to produce signals proportional to the average tension of the web. The spring biasing means 119 may be designed so that the sum of their displacements is substantially proportional to the average web tension or to the total web tension divided by the width of web being processed. Thus the sum of the displacements of the spring biasing means 119 may be made equal to the arithmetical average of the displacements

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of all spring biasing means 116. This relationship could be altered to accommodate other widths by employing a circuit wherein the voltage supplying the primary coils of the linear differential transformers 120 and/or 117 is varied to set up the desired proportional ratio in output signals generated by the respective linear differential transformers. By subtracting the average web tension signal from the individual lane tension signals by use of an electrical network, the resulting signals will be independent of variations in tension in the web processing equipment. By this means all lane tension measurements are obtained on a common basis independent of variations in the overall web tension and the resulting signals may provide a consistent quantitative indication of the web flatness.

In Figure 2 there is shown a detailed view of the individual lane tension measuring and overall web tension measuring means used in the embodiment shown in Figure 1. As disclosed in the discussion above, it consists of web feeler elements 114 interspaced with supporter elements 115. These supporter elements are used for the purpose of substantially eliminating the effect of adjacent lanes upon the individual lane being measured by supporting the sheet in a substantially common plane. The feeler elements 114 as well as the supporter elements 115 are each mounted upon spring biasing means 116 each of which is mounted upon base 121. The spring biasing means of each feeler element is connected to individual differential transformers 117 for the purpose of generating signals which are substantially directly proportional to the amount of tension existing in each one of the lanes being measured. Wires 122 and 123 are the input and output conducting means therefor.

For a fixed displacement of the feeler elements or sensing roll 114, into the web, the force exerted on the spring biasing means 116 is proportional to the tension of the lane being measured. Since each of the biasing means 116 is very stiff, only a small displacement occurs. Thus the force exerted on the spring biasing means is held substantially proportional to the tension of the lane. This small movement is detected by a differential transformer 117 which will generate a voltage proportional to such force.

The total average tension existing in the overall web is measured by adding the individual tensions of each lane in the web and taking their average. This may be accomplished rather simply by mounting each of the feeler elements upon a support 118 through the base and measuring the deflection of the base. One can, however, use other methods such as disclosed in Figure 3. To measure the deflection of the base the ends of the support 118 are mounted upon spring biasing means 119 which in turn are connected to differential transformers 120. Here again the signals generated by the differential transformers 120 are directly proportional to the forces exerted and since the forces exerted are the sum of the individual lane forces in each of the feeler and supporter elements, one obtains from these differential transformers 120 a signal directly proportional to the overall web force. Wires 124 and 125 are the input and output conducting means for the differential transformers.

In Figure 3 there is shown another embodiment of an overall tension measuring device that may be used for effecting the purpose of this invention. This embodiment is used where one does not desire to incorporate the individual lane tension measuring means upon the overall web tension measuring means. It consists of a web contact roll 321 mounted at its ends upon spring biasing means 322 and 323 respectively which in turn are each directly connected to differential transformers 324 and 325 respectively and are for the purpose of generating a signal directly proportional to the force exerted by the web. As shown, the armatures 326 and 327 of the linear differential transformers are each flexure mounted between flexible metal strips 328, 329 and 330, 331 respec-

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tively. Insulated wires 332, 333 and 334, 335 are the input and output conducting means for the differential transformers.

In Figure 4 there is shown a detailed view of a feeler element as mounted upon a spring biasing means and connected to a differential transformer. It consists of a feeler element 114 in the form of a roller mounted through its axle 411 to journals 412 which in turn are mounted upon spring biasing means 116. A support stock 121 is used as a base for affixing the spring biasing means, the differential transformer 117 and the flexure mounting for said transformer. Movement of the feeler element in either direction as shown by the arrows causes activation of the transformer. The differential transformer consists, as discussed in U. S. 808,944, U. S. 2,050,629 and U. S. 2,427,866, essentially of a primary coil 413, two secondary coils 414 and 415 and an armature of magnetic material 416. The primary coil is energized from a suitable source of alternating current by insulated electrical conduits 417 and 418. The two secondary coils communicate with insulated electrical conduits 419 and 420 and with each other by means of conduit 421 so that their output voltages are 180° out of phase. The armature is so located that it can alter the relative flux distribution which exists between the primary coil and the two secondary coils. Motion of the armature 416 toward secondary coil 414 results in an increased output of one phase while motion towards secondary coil 415 results in an increased output of the opposite phase. If 414 and 415 are identical coils and armature 416 is located so that each receives an equal amount of flux, the voltages induced in these secondary coils will be equal and out of phase and a theoretical output of zero will result. This condition denotes the null or balance point of the differential transformer. Hence, movement of the armature 416 caused by movement of the feeler element 114 will cause a generation of voltage proportional to the amount of movement. And since movement in this case is substantially proportional to the amount of tension exerted by the lane of material, one can obtain an indication of the tension or the lane length almost directly from said voltage.

In Figure 5 there is shown a detailed vertical sectional view of an arrangement of a feeler element and two supporter elements comprising a portion of the lane tension indicating means spread laterally across the width of the web. As shown in this drawing each feeler element consists of a roller 114 which contacts the web W. The roller is so mounted that it will activate the armature of a differential transformer through journals 412 and connecting support 511. As shown the feeler elements are alternated between supporting elements. These consist of rollers each numbered 115 mounted so that they will rotate as the web comes into contact with them. The distance between each of these rollers and the feeler elements is kept to a minimum to lessen the effect of adjacent lanes upon the lane being measured. Support for each of these supporting rollers consists of axles 512 in axle housings 513. These housings are directly connected to the spring biasing means of the support elements through connecting rods 514.

In Figure 6 there is shown an embodiment of a modified strip chart recorder that may be used in this invention. It consists of chart roll 611, driven by servo motor 612 through gears 613 and 614 and shaft 615. A spiral cam 616, connected to the end of shaft 615, activates differential transformer 619. A second cam 624 connected to shaft 615 activates a limit switch 617. Upon one complete revolution, limit switch 617 is tripped effecting the signal operating servo motor 612, and a new zero base line is thereby established for the next flatness recording. This is more completely described in the discussion which follows hereinafter. Hence, by such means separate successive flatness recordings may be recorded on the chart, each plotted directly above the preceding recording to permit a direct comparison.

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Pen 618, driven by fixed-speed pen drive motor 620, draws the line representing the sheet flatness upon the chart. The pen drive motor simultaneously by means of gears 622 and 623 drives selector switch 621, the purpose of which is more fully explained in the discussion of Figure 7.

In Figure 7 there is shown an embodiment of an electrical circuit that may be used in this invention. Two linear differential transformers 711 and 712 are mechanically coupled to the overall web tension measuring device various embodiments of which are shown in Figures 1, 2 and 3. Movements of their armatures by the spring biasing means results in an increased output of one of the two phases which said transformer generates as described hereinbefore.

Differential transformers 713, 714 and 715 and more if needed are mechanically coupled to the individual lane tension feeler elements. Here again movement of the armature results in an increased output of one of the two phases which said transformers are able to generate. The voltage developed by each of the individual lane tension measuring transformers is transmitted to a separate contact point of the selector switch 621 (see also Figure 6). Rotating contact 719 picks up these voltages individually as it revolves and transmits it to the secondary coils of the overall lane tension measuring transformers 711 and 712 which are connected in series in a manner so as to effect a subtraction of the sum of the voltages of the overall lane tension transformers from the voltage of the individual lane tension transformers. These differences in voltages are each compared with the voltage of the recorder sensing element which is shown as a linear differential transformer 619 (see also Figure 6). Any difference or error is amplified in amplifier 721 recorded on the strip chart recorder shown in Figure 6 and the position of the armature of linear differential transformer 619 automatically adjusted until the error has been reduced to zero at which time motor 612 stops. Motor 612 shown in the diagram is the servo motor which drives the chart roll 611 (see Figure 6).

The remainder of the circuit shown in Figure 7 is designed to provide web flatness recordings automatically at predetermined intervals. The movement of the selector switch 621 is started when a switch in timer 722 is closed. This energizes relays 723 and 724. Contacts are established in relay 723 which operates pen drive motor 620, also shown in Figure 6. This motor drives the pen across the chart from left to right and concurrently drives the scanning switch to pick up the output signals from the sensing devices. At the end of the pen travel, limit switch 725 is opened. This deenergizes the timer 722 and allows its switch to open. This in turn deenergizes relays 723 and 724. Relay 724 is constructed with a time delay after it is deenergized and motor 620 remains stationary while the recorder chart is indexed for the succeeding scan. This is accomplished when relay 723 is deenergized which disconnects the tension measuring linear differential transformers and substitutes a unit 726 having a fixed signal output. This signal output is too strong to be cancelled or nulled by the recorder sensing unit 619 and this, therefore, causes the chart drive motor 612 to rotate the chart until switch 617 is operated by means of cam 624 shown in Figure 6. The closing of switch 617 energizes relay 727 which disconnects the signal output unit 726 and substitutes unit 728 having an output which the recorder sensing unit 619 can balance. The value of the fixed signal from unit 728 may be used to establish a base line for the succeeding scan. Relay 727 remains energized until the start of the succeeding scan. By this means the chart rolls are indexed one complete turn and held in position until a succeeding scan starts.

After the chart roll has had time to index as described, the contracts on time delay relay 724 close energizing the

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pen drive motor 620 to drive from right to left. This releases limit switch 725 which allows current to enter the timer 722 starting the timing operation which will again operate the timer switch after a preset period of time has elapsed. When the pen drive motor 620 has driven the pen and the selector switch 621 back to the starting position on the left side, limit switch 729 is operated which again stops the pen drive motor. No further movement occurs until the timer switch again closes and the process described is repeated.

For operating the various linear differential transformers shown in Figure 7 an alternating current is supplied to the primary coil of each of the transformers through electrical conduits 716 and 717.

In operation, the web W travels either over or under (shown in Figure 1) the idler rolls 111 and 112. The individual lane tension measuring devices mounted either in conjunction with or separately from the overall web tension measuring devices of this invention are then displaced onto the web so that the web is, forced out of its regular line of travel. The web, therefore, in being displaced causes a displacement of each of the sensing and supporting rolls of the individual lane tension measuring device.

For a fixed displacement of the feeler element roll 114, the force exerted on the spring biasing means 116 will be substantially proportional to the tension of the lane being measured. The small displacement of the spring operates a linear differential transformer 117. Force exerted against the feeler element 114 is, therefore, directly converted into an electrical signal which is substantially proportional to the tension of the lane being measured.

It has been determined that the length of a measured lane at zero tension is made up of the length under tension minus the amount caused by stretching the web at this tension. This, it is believed, may be expressed as follows for values of tension within the elastic limit of the web material:

$$S_0 = \left(1 - \frac{T_1}{C}\right) \sqrt{L^2 + (2h)^2}$$

where

S_0 is the lane length between two supports at zero tension,
 L is the span between the supports in inches,
 h is the displacement at the sensing unit in inches,
 C is the elastic constant in pounds per inch of width per inch of length,
 T_1 is the tension of the measured lane in pounds per inch of width.

The length of the lane being measured may also vary as a function of the average tension or overall pull exerted by the processing machinery. In simpler terms, a change in average tension, while a scan across the sheet of film is taking place, will effect the result and alter the lane length reading. However, by securing a measure of the overall pull of the processing machine, using a spring loaded roller similar to the method used in the individual lane tension device a measure of average tension can be obtained. And by subtracting this average overall tension from the individual lane tensions, lane length measurements, which are not changed as a result of processing overall tension changes, are obtained which affect both the individual and average tensions equally.

The preceding equation then becomes:

$$S = \left(1 - \frac{T_1}{C} + \frac{T}{C}\right) \sqrt{L^2 + (2h)^2}$$

where

S is the lane length at average tension,
 T is the average tension in pounds per inch of width.

Since the variations in the displacement of the film at the sensing unit is small, the force F_1 then is substantially proportional to the tension T_1 and the average

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force F is substantially proportional to the average tension T . h may be considered as constant and the above equation may, therefore, be written as follows:

$$S = (K_1) [1 - K_2(F_1 - F)]$$

where K_1 and K_2 are constants.

As the web travels over the individual lane tension measuring device and overall web tension measuring devices, signals proportional to F and F_1 are generated. These signals may then be used to indicate or record the lane length by the use of a network which subtracts the lane tension measuring device signal from the average tension signal generated by the overall web tension measuring device.

Figure 7 shows a wiring diagram which accomplishes this result. The voltage proportional to the forces acting upon the overall measuring means are subtracted from the voltage proportional to the force acting upon the feeler elements. This is accomplished with a selector switch 621 which selects the individual lane tension to be subtracted from the overall web tension signal and the circuit is so constructed that a subtraction is accomplished. Thus, the recorded variable is proportional to $F_1 - F$ which, from the above equation, is related to the lane length S . Hence, a direct reading can be obtained of the lane length of each of the individual lanes in a web. By recording these values upon a chart recorder, such as shown in Figure 6, a graphic picture of the sheet flatness of the web is obtained.

Various modifications may be made in the devices used to accomplish the objects of the invention and, therefore, this disclosure of the invention should not be limited to the devices specifically described in detail. Some examples of other devices which may be used are as follows:

In place of the linear differential transformers, described herein for generating a signal proportional to the tensions being measured, one may also employ pneumatic force balance nozzles and diaphragms.

The individual lane and overall web linear differential transformers may be substituted with other known electrical transducers, such as microsensors, potentiometers, strain gauges, variable capacitors, etc.

If tension variations in the processing machinery are slight, the overall web tension indicator may be eliminated to produce a less complicated mechanism and operation.

The arrangement of the lane feeler elements and the supporter elements as shown in Figure 5 might also be varied according to the dictates of the process and machinery being used. For example, slip sleds may be employed for the supporter rolls 115 where slip and blocking problems encountered in web handling are minor.

The recorder shown in Figure 6 might also be substituted with another type. Examples of such substitutes are as follows:

Conventional strip chart type to record the variable on an "X" axis rather than on the "Y" axis as shown in Figure 6.

Conventional circular chart type to record the variable in a radial direction.

Where obvious to one skilled in the art, the circuit diagram arrangement might also be varied without departing from the spirit and scope of this invention.

The apparatus disclosed herein can be used upon various web materials to indicate sheet flatness. Among the webs for which this invention is particularly useful are plastic webs such as cellulose film, polyvinylidene chloride film, polyethylene film, polyethylene terephthalate film, rubber hydrochloride film and others. Webs other than plastic, such as rubber sheeting, paper, fabric, etc., may also have their sheet flatness determined with the use of the herein disclosed invention. Obviously, no general limitation should be imposed upon the type web which may be measured by the device of this invention.

As inferred above, while a detailed description of this invention has been provided, it is realized that those

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skilled in the art may make modifications and adaptations of the apparatus described without departing from the spirit and scope of this invention.

The invention having thus been described, what is claimed and desired to be secured by Letters Patent is as follows:

1. An apparatus for indicating the flatness of a web comprising resiliently mounted web lane tension sensing rolls disposed across the width of the web and interspaced with resiliently mounted web lane support rolls for supporting lanes of web adjacent the lane contacted by said sensing rolls, said sensing rolls and said support rolls being mounted upon a support bar, resiliently mounted supports for the support bar capable of being displaced proportionately to the average tension of the sum of said lane support rolls and said sensing rolls, said sensing rolls and said supports being each coupled to separate linear differential transformers which generate signals proportionate to the tension being encountered by said rolls and said supports and electrical coordinating means connected to said transformers for determining and recording the sheet flatness of the web from these signals.

2. An apparatus for indicating the flatness of a continuously advancing web comprising a plurality of tension sensing rolls and supporting rolls disposed alternately across the width of the web and in rolling contact with the web, a resiliently mounted support for carrying all said rolls, said supporting rolls being movable as a unit with said support, means resiliently supporting each said tension roll for movement relative to the supporting rolls whereby said supporting rolls move responsive to changes in tension occurring throughout the full width of the web while the tension sensing rolls move responsive to variations in tension occurring along predetermined widths of the web, and electrical circuit means connected to each said tension sensing roll and to said resiliently mounted support for converting the movement thereof into electric signals, said electric circuit including means to compare selectively the signal of each tension sensing roll to that of the supporting rolls.

3. An apparatus for indicating the flatness of a continuously advancing web comprising a plurality of tension sensing rolls and supporting rolls disposed alternately across the width of the web and in rolling contact with the web, a resiliently mounted support for carrying all said rolls, said supporting rolls being movable as a unit with said support, means resiliently supporting each said tension sensing roll for movement relative to the supporting rolls whereby said supporting rolls move responsive to changes in tension occurring throughout the full width of the web while the tension sensing rolls move responsive to variations in tension occurring along predetermined widths of the web, and electrical circuit means including armatures connected to each said tension sensing roll and to said resiliently mounted support for converting the movement thereof into electric signals, said electric circuit means including a rotary switch adapted to compare selectively the signals of the tension sensing rolls to that of the supporting rolls.

4. An apparatus for indicating the flatness of a continuously advancing web comprising a plurality of tension sensing rolls and supporting rolls disposed alternately across the width of the web and in rolling contact with the web, a resiliently mounted support for carrying all said rolls, said supporting rolls being movable as a unit with said support, means resiliently supporting each said tension sensing roll for movement relative to the supporting rolls whereby said supporting rolls move responsive to changes in tension occurring throughout the full width of the web while the tension rolls move responsive to variations in tension occurring along predetermined widths of the web, electrical circuit means including armatures connected to each said tension sensing rolls and to said resiliently mounted support for con-

verting the movement thereof into electric signals, said electric circuit means including a rotary switch adapted to compare selectively the signals of the tension sensing rolls to that of the supporting rolls and means for re-
cording the signals.

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