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Neugroschl

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[54] **SYSTEM AND METHOD FOR MONITORING QUALITY CHARACTERISTICS OF A MOVING WEB**

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[52] **U.S. Cl.** ..... **73/88 A**, 73/159, 73/356

[51] **Int. Cl.** **G01b 11/16**

[58] **Field of Search** ..... 73/143, 159, 88 A, 356; 23/230 LC; 117/37 R

[56] **References Cited**

UNITED STATES PATENTS

3,298,984	1/1967	Rye	260/29.3
3,533,399	10/1970	Goldberg	73/356

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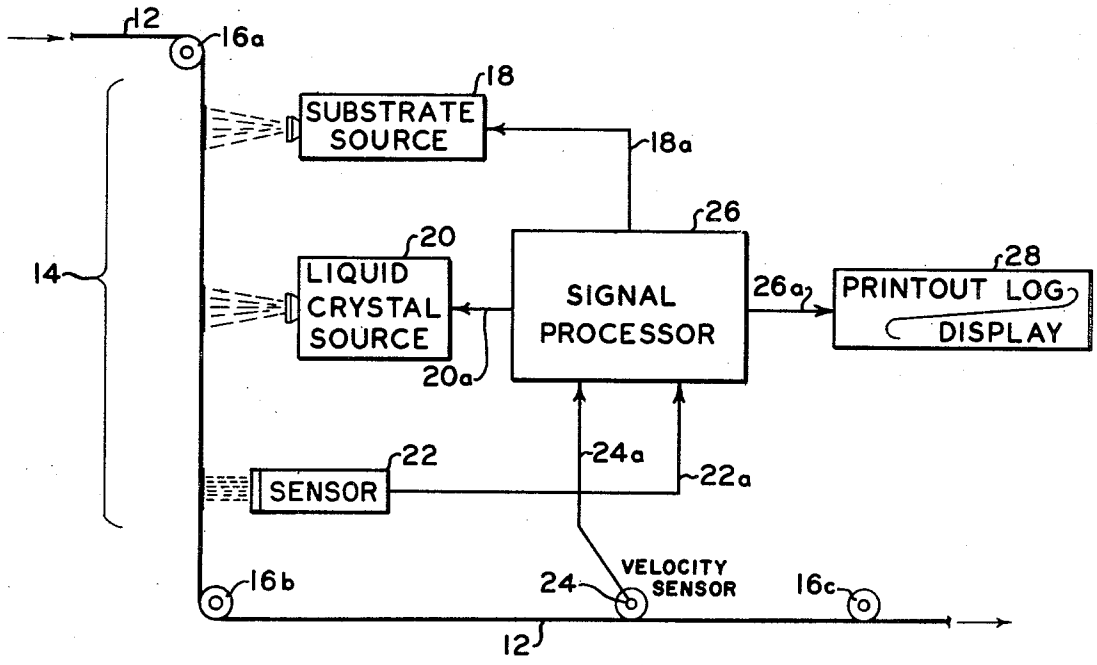
"Liquid Crystals," Scientific American, August 1964, by J. L. Ferguson, pp. 76–85.

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[57] **ABSTRACT**

On-line monitoring of a moving fabric web is accomplished by depositing stress or temperature sensitive liquid crystals on the web. The liquid crytals reflect radiant energy in response to the existing material stress or temperature that is detected by a sensor outputing electrical signals indicative of the wavelength of the radiant energy. The sensor signals are fed to a minicomputer and subsequently to a printout or display for process control or quality assurance purposes.

14 Claims, 2 Drawing Figures



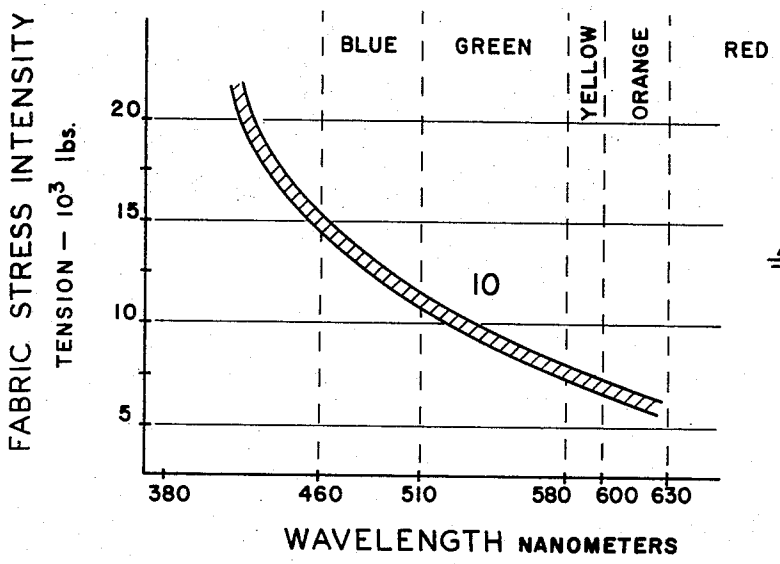

FABRIC STRESS INTENSITY
TENSION — 10^3 lbs.
20
15
10
5
BLUE
GREEN
YELLOW
ORANGE
RED
10
380
460
510
580
600
630
WAVELENGTH NANOMETERS

FIG - 1

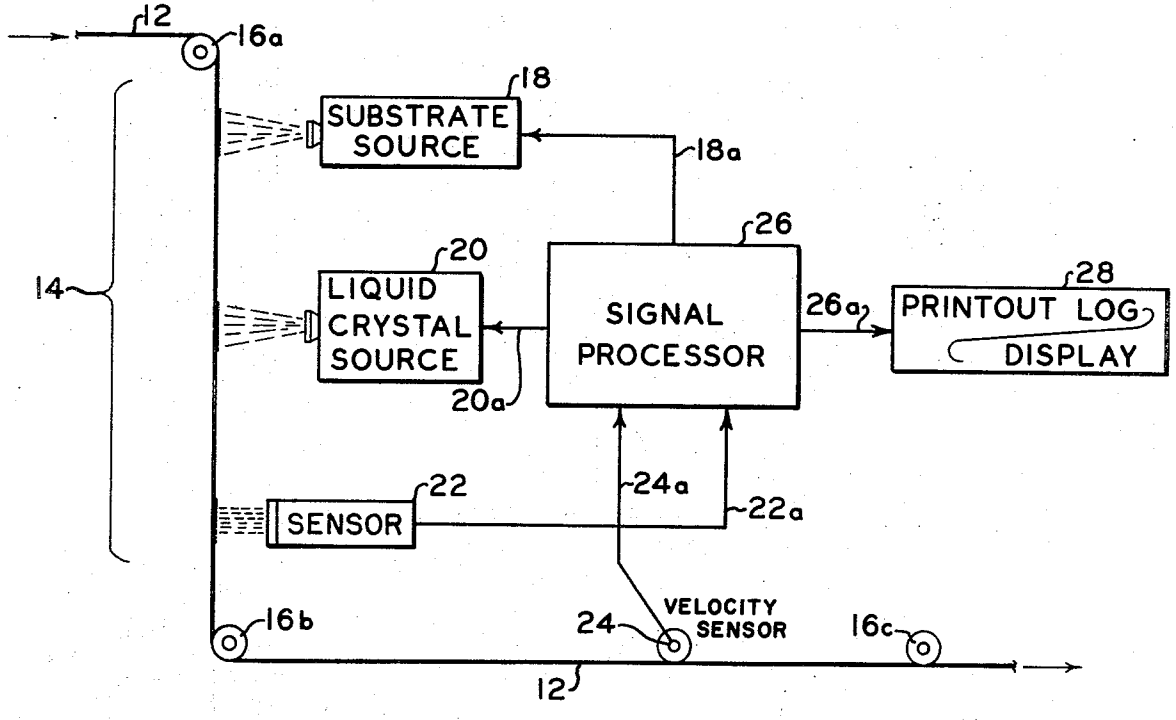

12
16a
18
SUBSTRATE SOURCE
18a
26
20
LIQUID CRYSTAL SOURCE
SIGNAL PROCESSOR
26a
28
PRINTOUT LOG
DISPLAY
14
20a
22
SENSOR
24a
22a
16b
24
VELOCITY SENSOR
16c
12

FIG - 2

SYSTEM AND METHOD FOR MONITORING QUALITY CHARACTERISTICS OF A MOVING WEB

This invention generally relates to monitoring a moving web of material and more specifically to a system and method utilizing the properties of liquid crystals to provide a stress or temperature profile of the web material.

The invention is based on findings that the molecular structure, light reflecting, and optical properties of cholesteric liquid crystals or compounds may be altered by mechanical stress or temperature. This is due to the relatively weak, intermolecular binding forces in these substances. The color spectrum reflectivity of the cholesteric substance in the low stress region is in the green or blue-green domain and shifts to the less intense blue domain by application of increased stress. These findings are generally known to persons skilled in the liquid crystal art and may be substantiated by reference to *Scientific American*, vol. 211, 1964, *Liquid Crystals* by J. L. Ferguson and The CRC Press, 1971, *Structure and Physical Properties of Liquid Crystals.*

In view of the beforementioned findings, it is also generally known that stress sensitive liquid crystals may be compounded to produce a specific stress region or force where the marked difference in terms of wavelength bandwidth is particularly pronounced and therefore easily differentiated by an optical scanner or sensor.

In the manufacture of a fabric and in particular a fabric later used in the ply stock for tires, a multistage, interconnected and continuous system is used to develop the fabric to a state for tire fabrication. In this process, various types of fabrics, such as nylon, rayon, cotton, polyester, wire mesh, or others of natural or synthetic origin, are coated, heated, and stretched or shrunk, to meet specific material specifications. The fabric is usually first dipped into a chemical rubber or adhesive-containing solution and fed onto rollers through several batteries of drying and heating ovens. During this run, the fabric is stretched by applying force on the guiding rollers or in some cases is permitted a controlled shrinkage. The variables that affect the fabric quality are the stretch, speed of traverse, exposure to heat and humidity, and the amount of dip-pickup of the fabric. The presently applied quality control check of the fabric involves various tests conducted on fibers removed from the fabric at the end of the finished roll. These tests, for example, may consist of conducting elongation and shear tests on several threads or cords extracted from the woven fabric and calculating the modulus of elasticity of the finished fabric. Since it is not possible, in a continuous sytem of the type described, to cut out samples of the fabric during processing without destroying the integrity of the roll or interrupting the process, continuous monitoring for quality control required improvement. In addition, temperature exposure of several stretches of fabric within a single roll may vary and test results of the sample taken at the roll's end do not necessarily indicate or reflect the quantitative quality values of the entire fabric roll.

Therefore, it is a primary object of this invention to overcome the aforementioned deficiencies in fabric testing for quality control by providing a system and method utilizing the beforementioned properties of liquid crystals to effect on-line fabric quality testing.

Another object of the invention is to provide a means for continuously and accurately measuring the quality of a moving fabric web without making physical contact therewith.

These objects, and other objects and advantages, are provided in a system to control the quality of a fabric material comprising (a) means to coat the fabric with a black, absorptive background substrate, (b) means to sense the velocity of the moving fabric, (c) a source of liquid crystals, (d) means to control the application of the liquid crystals such that the application is made over the black, absorptive substrate, (e) means to sense the wavelength of the radiant energy reflected by the liquid crystals in response to the existing fabric stress, and (f) means to provide a continuous record of the fabric quality as it is rolled and processed.

DESCRIPTION OF THE DRAWINGS

The features and advantages of the invention may best be understood by reference to the description that follows in conjunction with the accompanying drawings in which:

FIG. **1** is a graph of stress intensity, versus wavelength of reflected radiant energy from a liquid crystal film, and

FIG. **2** is a diagrammatic illustration of the invention as used to determine the stress profile in a moving fabric web of material.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** illustrates a stress intensity vs. wavelength curve **10** as may be applied to cholesteric liquid crystal substances showing the variation in radiant energy reflectivity as a function of tension. From the graph, it may be concluded that by applying stress-sensitive liquid crystals to a structure and sensing the reflected radiant energy, one might establish the degree of stress within the structure. In the instant case, the structure is a web of material or fabric and if, for example, it is desired to maintain a tension on the material within the range of 10,000–15,000 pounds, then a liquid crystal composition may be compounded for this specific stress region and may be applied to the material for a stress test of the material. If, in the above example, the tension in the web at the area of application remains within the beforementioned stress region, then the radiant energy reflected by the crystals will be within the 460 to 510 nanometer wavelength and a sensor, sensitive to this band, may be used to determine whether the material tension is in the desired region.

FIG. **2** generally illustrates a system for on-line testing of a fabric web. In the drawing, a web of material **12** passes through a testing zone generally indicated at **14** via rollers **16***a*, **16***b*, and **16***c*. In the test zone are located, a source for a substrate spray **18**, a source for a liquid crystal spay **20**, an optical sensor **22**, and a web velocity sensor **24**. Each of the apparatuses **18**, **20**, **22**, and **24** are coupled to a minicomputer or processor **26** that ties the system operation together as will be more fully described hereinafter and outputs a signal indicative of the existing stress in the material to a printout log or display **28**.

The substrate **18** is preferably a black adhesive material of the type as described in a U.S. Pat No. 3,298,984 by G. W. Rye, and assigned to The Goodyear Tire & Rubber Company, Akron, Ohio, and provides a sub-

stantially constant density background for the application of the liquid crystals. In its form as a black substrate background, the material enhances the reflectivity of the crystals while also performing the function of a carrier for the crystal spray.

Of course, it is realized that if the web were a close-woven material and exhibited a substantially constant density background, then there would be no need for the application of a substrate and, therefore, it is not considered a requirement of the instant invention.

It is also recognized that the application of the substrate and liquid crystal composition may be made by other means such as rollers, film applicator, doctor blade, etc. However, in the preferred embodiment spraying is the recommended means since it facilitates precise control by the minicomputer **26** and may be applied without making contact with the web **12.**

In operation, the web of fabric material **12** is moving at constant velocity through the test zone **14.** A velocity sensor **24** feeds an input signal **24***a* to the minicomputer **26** that provides control signals to the sprayers **18** and **20** via lines **18***a* and **20***a*, respectively. At time *t* the computer initiates a signal to the substrate sprayer **18** and an amount of substrate is applied to the moving web of material. At time $t + n$ the computer initiates another control signal to the liquid crystal sprayer **20** and a film of stress-sensitive liquid crystals is applied over the substrate. The timing of the spray applications is dependent on the velocity of the moving web and the distance between the applicators **18** and **20** and may be adjusted by the minicomputer control signals to meet any particular situation. Also, the distance between each test along the length of the web is adjustable and under the control of the minicomputer. For example, it may be desired to test the web at 10-foot intervals and the minicomputer may be set up to initiate a test sequence for every 10-foot interval along the length of the material.

As the web of material moves downstream, an optical sensor **22** effects an output signal on line **22***a* that is indicative of the radiant energy reflected by the stress-sensitive liquid crystals. Here again, a number of options are available. For example, the sensor may be bandwidth limited to the less intense blue region and outputs a signal in response to this radiation wavelength. If the liquid crystal spray is compounded to reflect radiant energy of this wavelength in response to the corresponding stress intensity, then as long as the material exhibits a stress intensity within this range, the sensor will provide an output to the minicomputer. If, on the other hand, the material stress intensity is outside of this range, the sensor will not be provided a detectable input and no corresponding signal will be sent to the minicomputer.

The minicomputer, upon receiving signals from the sensor **22,** provides a signal output on line **26***a* to the printout log **28.** The printout may be in the form of a strip recorder tied to the length of the web and its velocity to provide a permanent test record of the finished roll. As in the case with fabric material for use in the ply stock for tires, the fabric is accumulated on rolls for shipment and a strip chart from **28** may be attached to each roll for a stress record of the fabric on the roll. The apparatus **28** may also include a visual display that would be helpful to personnel operating the mill so that adjustments to the process upstream of the testpoint may be made to bring the fabric within desired quality limits.

Other alternatives to the above operation will become apparent to persons skilled in the art. For example, the liquid crystals may not be compounded to a specific bandwidth but may reflect radiant energy of a wavelength dependent on the specific stress intensity of the fabric at the test point. In this circumstance, the sensor **22** may be adapted to be sensitive to any wavelength and will output signals indicative of the specific radiant energy reflected by the liquid crystals. In this manner, the minicomputer and the printout-log/display provide stress readings for every test point along the length of the fabric.

In another alternative application, the liquid crystals may be of a temperature sensitive type exhibiting different optical properties in response to temperature variations. Liquid crystals of this type are well known in the art by knowledgeable persons and such an adaptation is considered an obvious alternative in view of the teaching using stress-sensitive liquid crystals.

While certain representative embodiments and details have been shown for the purpose of illustrating the invention, it will be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit or scope of the invention.

What is claimed is:

1. A system for monitoring the quality characteristics of a moving web comprising:

A. a source of liquid crystals compounded to reflect radiant energy in response to stress;

B. means to apply the liquid crystals to the surface of the web;

C. sensor means responsive to the reflected radiant energy from the liquid crystals on the web to provide signals indicative of the stress in the web as exhibited by the wavelength of the reflected energy;

D. a velocity sensor positioned relative to the web to provide an output signal indicative of the web speed; and

E. a signal processor operatively connected to the velocity sensor, the means applying the liquid crystals, and the sensor means, to provide control signals in response to the web velocity such that the liquid crystals may be selectively applied at intervals along the length of the web and to receive the output of the sensor means to provide signals indicative of the web stress profile.

2. The system according to claim **1** further comprising:

a. a source of a black absorptive substrate to provide a constant density background for the liquid crystals; and

b. means positioned relative to the web to apply the substrate to the surface of the web in advance of the liquid crystal application.

3. The system according to claim **2,** wherein the signal processor also provides control signals to the means applying the substrate material such that the substrate and crystals are applied at select intervals along the length of the web, said crystals being applied over the substrate material.

4. The system according to claim **1** further comprising means coupled to the signal processor to accept the signals indicative of the web stress profile and provide a printed readout thereof.

5. The system according to claim **4** wherein the means coupled to the signal processor to accept the sig-

nals indicative of the web stress profile provides a visual display thereof.

6. A system for monitoring the stress profile of a moving fabric web comprising:

A. a source of liquid crystals compounded to reflect radiant energy in response to stress;

B. means to spray the liquid crystals on the surface of the fabric web;

C. a source of a substrate material to provide a constant density background on the fabric web;

D. means to spray the substrate material on the fabric web;

E. sensor means in relative position to the surface of the moving web to receive the reflected radiant energy from the liquid crystals and responsive to said energy to provide an output signal indicative of the wavelength of the radiant energy;

F. a velocity sensor in relative position to the web to provide output signals indicative of the web speed; and

G. a minicomputer coupled to the velocity sensor, the means to spray the liquid crystals, and the means to spray the substrate material, to provide control signals to said spray means such that the liquid crystals are applied over the substrate material, said minicomputer also accepting the output signals from the sensor means to provide an output representative of the web stress profile useful for quality control or display.

7. The system according to claim **6** wherein the liquid crystals are compounded to reflect radiant energy within the 460–520 nanometer wavelength, the sensor is bandwidth limited to the reflected energy, and the minicomputer outputs control signals for online process quality control when the existing web stress exceeds the response limits of the liquid crystals.

8. The system according to claim **6** wherein the liquid crystals are compounded to reflect radiant energy within the visible light spectrum, the sensor is bandwidth limited to output electrical signals in response to radiant energy within 460 to 520 nanometer wavelengths, and the minicomputer converts the signals from the sensor to an output representation of the web stress profile.

9. A method of monitoring the stress quality characteristic of a moving web of material comprising the steps of:

A. providing a source of liquid crystals compounded to reflect radiant energy in response to stress;

B. applying the liquid crystals to the web;

C. controlling the application of the liquid crystals by feeding velocity signals from a web speed sensor to a minicomputer such that said crystals are applied at select intervals along the length of the web;

D. optically sensing the wavelength of the radiant energy reflected from the liquid crystals on the web to provide output electrical signals indicative of the radiant energy wavelength; and

E. converting the electrical signals indicative of the radiant energy wavelength to a display of the stress profile of the web.

10. The method of claim **9** further comprising the steps of:

A. providing a source of a black adhesive coating; and

B. applying the black adhesive coating to the web in advance of the liquid crystals to provide a means to hold the crystals on the web and to provide a substantially constant density background to enhance the reflectivity of the liquid crystals.

11. The method of claim **10** wherein the black adhesive coating and the liquid crystals are applied at intervals along the length of the web, said crystals applied over the black adhesive coating and the timing of said applications controlled by signals from the minicomputer being fed velocity signals from the web speed sensor.

12. A system for monitoring the quality characteristics of a moving web comprising:

A. a source of liquid crystals compounded to reflect radiant energy in response to temperature;

B. means to apply the liquid crystals to the surface of the web;

C. sensor means responsive to the reflected radiant energy from the liquid crystals on the web to provide signals indicative of the temperature in the web as exhibited by the wavelength of the reflected energy;

D. a velocity sensor positioned relative to the web to provide an output signal indicative of the web speed; and

E. a signal processor operatively connected to the velocity sensor, the means applying the liquid crystals, and the sensor means, to provide control signals in response to the web velocity such that the liquid crystals may be selectively applied at intervals along the length of th web and to receive the output of the sensor means to provide signals indicative of the web temperature profile.

13. A system for monitoring the temperature profile of a moving fabric web comprising:

A. a source of liquid crystals compounded to reflect radiant energy in response to temperature;

B. means to spray the liquid crystals on the surface of the fabric web;

C. a source of a substrate material to provide a constant density background on the fabric web;

D. means to spray the substrate material on the fabric web;

E. sensor means in relative position to the surface of the moving web to receive the reflected radiant energy from the liquid crystals and responsive to said energy to provide an output signal indicative of the wavelength of the radiant energy;

F. a velocity sensor in relative position to the web to provide output signals indicative of the web speed; and

G. a minicomputer coupled to the velocity sensor, the means to spray the liquid crystals, and the means to spray the substrate material, to provide control signals to said spray means such that the liquid crystals are applied over the substrate material, said minicomputer also accepting the output signals from the sensor means to provide an output representative of the web temperature profile useful for quality control or display.

14. A method of monitoring the temperature quality characteristic of a moving web of material comprising the steps of:

A. providing a source of liquid crystals compounded to reflect radiant energy in response to temperature;

B. applying the liquid crystals to the web;

C. controlling the application of the liquid crystals by feeding velocity signals from a web speed sensor to a minicomputer such that said crystals are applied at select intervals along the length of the web;

D. optically sensing the wavelength of the radiant energy reflected from the liquid crystals on the web to provide output electrical signals indicative of the radiant energy wavelength; and

E. converting the electrical signals indicative of the radiant energy wavelength to a display of the temperature profile of the web.

* * * * *