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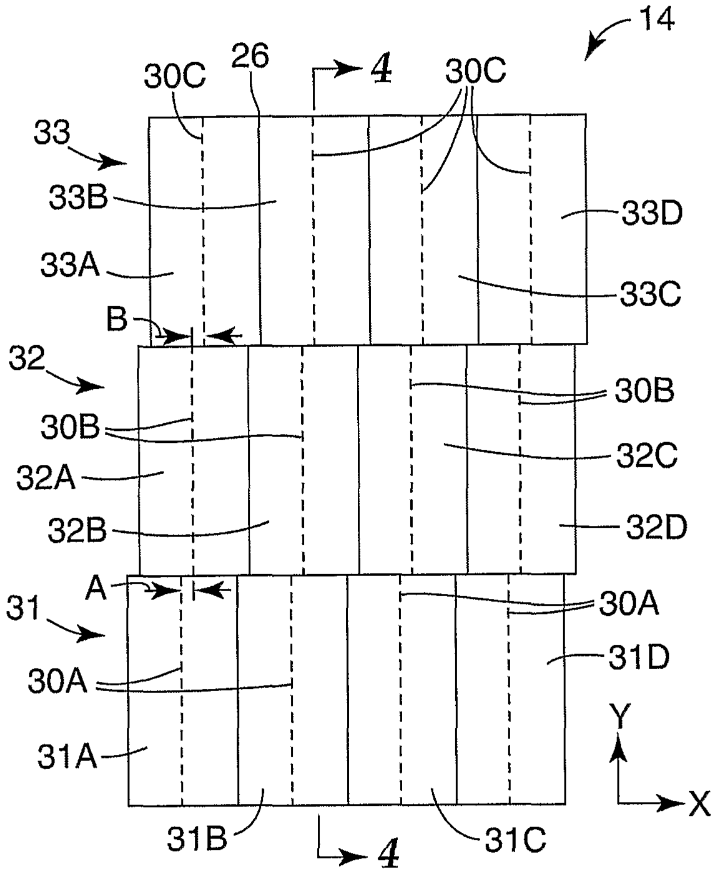
(54) Title: MICROREPLICATED ARTICLE WITH MOIRE REDUCING SURFACE



(57) Abstract: A microreplicated article having a moiré reducing surface and method of manufacturing the same, are disclosed. A microreplicated article includes a flexible substrate having first and second opposed surfaces, a first coated microreplicated pattern on the first surface, and a second coated microreplicated pattern on the second surface. The first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 10 micrometers in a machine direction and a transverse direction and the first coated microreplicated pattern and second coated microreplicated pattern form a plurality of lens segments. Each lens segment includes a plurality of lens elements each having an optical axis where all of the lens element optical axes are parallel to each other and lens elements within a first lens segment have optical axes that are offset from optical axes of lens elements within an adjacent second lens segment.

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MICROREPLICATED ARTICLE WITH MOIRÉ REDUCING SURFACE

Field

The disclosure relates generally to the continuous casting of material onto a web, and more specifically to the casting of articles having a moiré reducing surface and a high degree of registration between the patterns cast on opposite sides of the web.

Background

In the fabrication of many articles, from the printing of newspapers to the fabrication of sophisticated electronic and optical devices, it is necessary to apply some material that is at least temporarily in liquid form to opposite sides of a substrate. It is often the case that the material applied to the substrate is applied in a predetermined pattern; in the case of e.g. printing, ink is applied in the pattern of letters and pictures. It is common in such cases for there to be at least a minimum requirement for registration between the patterns on opposite sides of the substrate.

When the substrate is a discrete article such as a circuit board, the applicators of a pattern may usually rely on an edge to assist in achieving registration. But when the substrate is a web and it is not possible to rely on an edge of the substrate to periodically refer to in maintaining registration, the problem becomes a bit more difficult. Still, even in the case of webs, when the requirement for registration is not severe, e.g. a drift out of perfect registration of greater than 100 micrometers is tolerable, mechanical expedients are known for controlling the material application to that extent. The printing art is replete with devices capable of meeting such a standard.

However, in some products having patterns on opposite sides of a substrate, a much more accurate registration between the patterns is required. In such a case, if the web is not in continuous motion, apparatuses are known that can apply material to such a standard. And if the web is in continuous motion, if it is tolerable, as in e.g. some types of flexible circuitry, to reset the patterning rolls to within 100 micrometers, or even 5 micrometers, of perfect registration once per revolution of the patterning rolls, the art still gives guidelines about how to proceed.

However, in e.g. optical articles such as brightness enhancement films, it is required for the patterns in the optically transparent polymer applied to opposite sides of a substrate to be out of registration by no more than a very small tolerance at any point in the tool rotation. Thus far, the art is silent about how to cast a patterned surface on opposite sides of a web that is in continuous motion so that the patterns are kept continuously, rather than intermittently, in registration within 100 micrometers.

One problem with using films in a display is that the cosmetic requirements for a display intended for close viewing, such as a computer display, are very high. This is because such displays are viewed closely for long periods of time, and so even very small defects may be detected by the naked eye, and cause distraction to the viewer. The elimination of such defects can be costly in both inspection time and in materials.

Defects are manifested in several different ways. There are physical defects such as specks, lint, scratches, inclusions etc., and also defects that are optical phenomena. Among the most common optical phenomena are moiré fringes. Moiré fringes are an interference pattern that is formed when two similar grid-like patterns are superimposed. They create a pattern of their own that does not exist in either of the originals. The result is a series of fringe patterns that change shape when the grids are moved relative to one another.

Several approaches have been followed to overcome the problem of defects in display assemblies. One is simply to accept a low yield of acceptable display assemblies produced by the conventional manufacturing process. This is obviously unacceptable in a competitive market. A second approach is to adopt very clean and careful manufacturing procedures, and impose rigid quality control standards. While this may improve the yield, the cost of production is increased to cover the cost of clean facilities and inspection. Another approach to reducing defects is to introduce a diffuser to the display, either a surface diffuser or a bulk diffuser. Such diffusers may mask many defects, and increase the manufacturing yield at low additional cost. However, the diffuser scatters light and decreases the on-axis brightness of light perceived by the viewer, thus reducing the performance.

Summary

One aspect of the present disclosure is directed to a microreplicated article having a moiré reducing surface. A microreplicated article includes a flexible substrate having first and second opposed surfaces, a first coated microreplicated pattern on the first surface, and a second coated microreplicated pattern on the second surface. The first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 10 micrometers in a machine direction and a transverse direction and the first coated microreplicated pattern and second coated microreplicated pattern form a plurality of lens segments. Each lens segment includes a plurality of lens elements. Each lens element has an optical axis where all of the lens element optical axes are parallel to each other and lens elements within a first lens segment have optical axes that are offset from optical axes of lens elements within an adjacent second lens segment.

In some embodiments, each lens element has four rectilinear sides, and the first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 10 micrometers for each of the four sides of each lens element. In some embodiments, adjacent lens segments lens element optical axis are offset from each other by 20 micrometers or less. Each lens segment lens element optical axis can be offset by a constant distance, a random distance or a pseudo-random distance.

Methods of making a microreplicated articles are also disclosed. The methods include the steps of providing a substrate, in web form, having first and second opposed surfaces, and passing the substrate through a roll to roll casting apparatus to form a first coated microreplicated pattern on the first surface and a second coated microreplicated pattern on the second surface. The first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 10 micrometers and the first coated microreplicated pattern and second coated microreplicated pattern form a plurality of lens segments. Each lens segment includes a plurality of lens elements. Each lens element has an optical axis where all of the lens element optical axes are parallel to each other and lens elements within a first lens segment have optical axes that are offset from optical axes of lens elements within an adjacent second lens segment.

Definitions

In the context of this disclosure, "registration," means the positioning of structures on one surface of the web in a defined relationship to other structures on the opposite side of the same web.

In the context of this disclosure, "web" means a sheet of material having a fixed dimension in one direction and either a predetermined or indeterminate length in the orthogonal direction.

In the context of this disclosure, "continuous registration," means that at all times during rotation of first and second patterned rolls the degree of registration between structures on the rolls is better than a specified limit.

In the context of this disclosure, "microreplicated" or "microreplication" means the production of a microstructured surface through a process where the structured surface features retain an individual feature fidelity during manufacture, from product-to-product, that varies no more than about 100 micrometers.

Brief Description of the Drawings

In the several figures of the attached drawing, like parts bear like reference numerals, and:

FIG. 1 illustrates a schematic cross-sectional view of an illustrative display;

FIG. 2 illustrates a schematic cross-sectional view of a microreplicated film according to the present disclosure;

FIG. 3 illustrates a top view of an illustrative microreplicated film according to the present disclosure;

FIG. 4 illustrates a schematic cross-sectional view of the illustrative microreplicated film of **FIG. 3** taken along line 4-4;

FIG. 5 illustrates a perspective view of an example embodiment of a system including a system according to the present disclosure;

FIG. 6 illustrates a close-up view of a portion of the system of **FIG.** 5 according to the present disclosure;

FIG. 7 illustrates another perspective view of the system of **FIG.** 5 according to the present disclosure;

FIG. 8 illustrates a schematic view of an example embodiment of a casting apparatus according to the present disclosure;

FIG. 9 illustrates a close-up view of a section of the casting apparatus of **FIG. 8** according to the present disclosure;

FIG. 10 illustrates a schematic view of an example embodiment of a roll mounting arrangement according to the present disclosure;

FIG. 11 illustrates a schematic view of an example embodiment of a mounting arrangement for a pair of patterned rolls according to the present disclosure;

FIG. 12 illustrates a schematic view of an example embodiment of a motor and roll arrangement according to the present disclosure;

FIG. 13 illustrates a schematic view of an example embodiment of a means for controlling the registration between rolls according to the present disclosure; and

FIG. 14 illustrates a block diagram of an example embodiment of a method and apparatus for controlling registration according to the present disclosure.

Detailed Description

Generally, the disclosure of the present disclosure is directed to a flexible substrate coated with microreplicated patterned structures on each side. The microreplicated articles are registered with respect to one another to a high degree of precision. Preferably, the structures on opposing sides cooperate to give the article optical qualities as desired, and more preferably, the structures are a plurality of lenses that includes a moiré reducing feature.

FIG. 1 illustrates a schematic cross-sectional view of an illustrative display **1**. In the illustrated embodiment, the display **1** includes one or more light sources **10a, 10b** providing light to an optical film **14**. The display **1** can include one or more additional optical components, as desired. Additional optical components can include, for example, a light guide **12** disposed between the one or more light sources **10a, 10b** and the optical film **14** and a liquid crystal cell **16** disposed adjacent to the optical film **14**. The liquid crystal cell **16** includes a plurality of pixel columns that are parallel to at least selected lens element's optical axis. In some embodiments, at least selected lens elements are parallel with but not aligned with the pixel columns. Staggering adjacent lens elements in relation to the pixel column can help reduce the occurrence of moiré fringes. The optical film **14** described herein can be used a variety of applications, as desired.

In some embodiments, the optical film **14** can be used in stereoscopic liquid crystal displays. One illustrative stereoscopic liquid crystal display is described in "Dual Directional Backlight for Stereoscopic LCD," Sasagawa et al., 1-3, SID 03 Digest, 2000. As shown in **FIG. 1**, the display **1** includes a right eye light source **10a** and a left eye light source **10b**. In the illustrated embodiment, the lights sources **10a, 10b** operate at a field rate of 120 Hz and a frame rate of 60 Hz, thus parallax images are displayed separately to the right eye when the right eye light source **10a** is illuminated and to the left eye when the left eye light source **10b** is illuminated, causing the perceived image to appear in three dimensions.

FIG. 2 illustrates a schematic cross-sectional view of an illustrative microreplicated optical film **14** according to the present disclosure. The optical film **14** includes a web substrate **20** having a first surface **22** and an opposing second surface **24**. A first coated microreplicated pattern or structure **25** is disposed on the substrate **20** first surface **22**. A second coated microreplicated pattern or structure 35 is disposed on the substrate **20** second surface **24**. In the illustrated embodiment, the first coated microreplicated pattern or structure **25** comprises a plurality of curved or cylindrical lenses and the second first coated microreplicated pattern or structure **35** comprises a plurality of prism lenses.

The optical film **14** can have any useful dimensions. In some embodiments, the optical film **14** has a height **T** from 50 to 500 micrometers, or from 75 to 400 micrometers, or from 100 to 200 micrometers. The first coated microreplicated pattern **25** and the second microreplicated pattern **35** can have the same repeating pitch or period **P**. In some embodiments, the repeating pitch or period **P** can be 25 to 200 micrometers, or 50 to 150 micrometers, as desired. The repeating pitch or period **P** can form a plurality of lens elements. Each lens element can join an adjacent lens element at a first joining point **26** and a second joining point **36**. In some embodiments, the first joining point **26** and second joining point **36** are adjacent to the substrate **20** and in registration. In other embodiments, the first joining point **26** and second joining point **36** are registered in a defined geometrical relationship that may not be adjacent one another across (z-direction) the web

20. The substrate **20** can have any useful thickness T_1 such as for example, 10 to 150 micrometers, or from 25 to 125 micrometers. The first microreplicated pattern **25** can have any thickness T_6, such as for example, from 10 to 50 micrometers and a feature or structure thickness T_3 from 5 to 50 micrometers. The second microreplicated pattern **35** can have any thickness T_5, such as for example, from 25 to 200 micrometers and a feature or structure thickness T_2 from 10 to 150 micrometers. A joining point thickness T_4 can be any useful amount such as, for example, from 10 to 200 micrometers. The curved lenses can have any useful radius **R** such as for example, from 25 to 150 micrometers, or from 40 to 70 micrometers.

In the example embodiment shown, opposed microreplicated features **25, 35** cooperate to form a plurality of lens elements. Since the performance of each lens element is a function of the alignment of the opposed features **25, 35** forming each lens element, precision alignment or registration of the lens features is preferable.

Generally, the optical film **14** of the present disclosure can be made by a system and method, disclosed below, for producing two-sided microreplicated structures registered in both the x-axis (machine direction "MD") and an orthogonal y-axis (transverse or cross-web direction "TD") lying in the plane of the substrate **20** of each lens element can be better than about 10 micrometers, or better than 5 micrometers, or better than 3 micrometers, or better than 1 micrometer. The system generally includes a roll to roll casting assembly and includes a first patterning assembly and a second patterning assembly. Each respective assembly creates a microreplicated pattern on a respective surface of a web having a first and a second surface. A first pattern is created on the first side of the web and a second pattern is created on the second surface of the web. A moiré reducing feature can be included with the first and/or second microreplicated pattern. The moiré reducing feature illustrated in **FIG. 3** and **FIG. 4** includes a plurality of lens segments having parallel but offset optical axes.

FIG. 3 illustrates a top view of an illustrative microreplicated film **14** according to the present disclosure. **FIG. 4** illustrates a schematic cross-sectional view of the illustrative microreplicated film **14** of **FIG. 3** taken along line **4-4**. The illustrated optical film **14** includes a first lens segment **31** including four lens elements **31A, 31B, 31C, 31D** arranged adjacent to each other along an X-axis and each having parallel optical axes **30A.**

A second lens segment **32** is disposed adjacent to the first lens segment **31**. The second lens segment **32** includes four lens elements **32A, 32B, 32C, 32D** arranged adjacent to each other along an X-axis and each having parallel optical axes **30B**. The first lens segment **31** lens element **31A, 31B, 31C, 31D** optical axes **30A** are parallel with, but offset by a distance **A** from the second lens segment **32** lens element **32A, 32B, 32C, 32D** optical axis **30B**. A third lens segment **33** is disposed adjacent to the second lens segment **32**. The third lens segment **33** includes four lens elements **33A, 33B, 33C, 33D** arranged adjacent to each other along an X-axis and each having parallel optical axes **30C**. The second lens segment **32** lens element **32A, 32B, 32C, 32D** optical axes **30B** are parallel with, but offset by a distance **B** from the third lens segment **33** lens element **33A, 33B, 33C, 33D** optical axis **30C**. The distance **A** and **B** can be a constant value or a random value or a pseudo-random value along either or both the positive x-axis and/or negative x-axis. In some embodiments, the distance **A** and **B** are within a predetermined value from 0.5 to 50 micrometers, or from 1 to 25 micrometers, or from 3 to 20 micrometers.

It is understood that while only three lens segments are illustrated in **FIG. 3** and **FIG. 4,** the optical film **14** can include any number of lens segments. The lens elements of each lens segment can have any width along the Y-axis. In some embodiments, the lens segment and lens elements have a length along the Y-axis equal to 1 to 100 times or 3 to 20 times the pitch **P** (along the X-axis) of each lens element. In some embodiments, the lens segment and lens elements have a length along the Y-axis in a range from 250 to 2000 micrometers, or from 500 to 1500 micrometers.

The moiré reducing feature can be a regular or random pattern that can be formed by the roll to roll casting apparatus and method described below. The moiré reducing feature can be formed onto master rolls described below by any method. In one embodiment, the moiré feature is formed onto the master rolls with known diamond turning techniques.

Masters for the tools (rolls) used for manufacturing the roll to roll cast optical films described herein, may be made by known diamond turning techniques. Typically the tools are made by diamond turning on a cylindrical blank known as a roll. The surface of the roll is typically of hard copper, although other materials may be used. The microreplication structures are formed in continuous patterns around the circumference of the roll. If the structures to be produced have a constant pitch, the tool will move at a constant velocity. A typical diamond turning machine will provide independent control of the depth that the tool penetrates the roll, the horizontal and vertical angles that the tool makes to the roll and the transverse velocity of the tool. In order to produce the moiré reducing feature microreplicated structures of the disclosure a fast tool servo actuator can be added to the diamond turning apparatus.

An illustrative fast tool servo actuator is described in US 6,354,709. This reference describes a diamond tool supported by a piezoelectric stack. When the piezoelectric stack is stimulated by a varying electrical signal, it causes the diamond tool to be moved such that the distance that it extends from the case changes. It is possible for the piezoelectric stack to be stimulated by a signal of constant or programmed frequency, but it is generally preferable to use a random or pseudo random frequency. As used herein, the term random will be understood to include pseudo random. The master tool (roll) so produced may then be used in the roll to roll cast and cure processes described below to produce the optical film described herein.

The moiré reducing optical film **14** described above can be made using an apparatus and method for producing precisely aligned microreplicated structures on opposed surfaces of the web, the apparatus and methods which are described in detail below. In one embodiment the web or substrate is made from polyethylene terephthalate (PET), 0.0049 inches thick. In other embodiments, other web materials can be used, for example, polycarbonate.

A first microreplicated structure can be made on a first patterned roll by casting and curing a curable liquid onto the first side of the web. In one embodiment, the first curable liquid can be a photocurable acrylate resin solution including photomer 6010, available from Cognis Corp., Cincinnati, Ohio; SR385 tetrahydrofurfuryl acrylate and SR238 (70/15/15 %) 1,6-hexanediol diacrylate, both available from Satomer Co., Expon, Pennsylvania; Camphorquinone, available from Hanford Research Inc., Stratford, Connecticut; and Ethyl-4-dimethylamino Benzoate (0.75/0.5 %), available from Aldrich Chemical Co., Milwaukee, Wisconsin. The second microreplicated structure can be made on a second patterned roll by casting and curing a photocurable liquid onto the second side of the web. The second curable liquid can be the same as the first curable liquid.

After each respective structure is cast into a pattern, each respective pattern is cured using a curing light source including an ultraviolet light source. A peel roll can then be used to remove the microreplicated article from the second patterned roll. Optionally, a release agent or coating can be used to assist removal of the patterned structures from the patterned tools.

Illustrative process settings used to create an article described above are as follows. A web speed of about 1.0 feet per minute with a web tension into and out of casting apparatus of about 2.0 pounds force. A peel roll draw ratio of about 5% to pull the web off the second patterned tool. A nip pressure of about 4.0 pounds force. A gap between the first and second patterned rolls of about 0.010 inches. Resin can be supplied to the first surface of the web using a dropper coating apparatus and resin can be supplied to the second surface at a rate of about 1.35 ml/min, using a syringe pump.

Curing the first microreplicated structure can be accomplished with an Oriel 200-500 W Mercury Arc Lamp at maximum power and a Fostec DCR II at maximum power, with all the components mounted sequentially. Curing the second microreplicated structure can be accomplished with a Spectral Energy UV Light Source, a Fostec DCR II at maximum power, and an RSLI Inc. Light Pump 150 MHS, with all the components mounted sequentially.

The first patterned roll can include a series of negative images for forming cylindrical lenses with a 75 micrometer pitch. The second patterned roll included a series of negative images for forming a plurality of symmetric prisms at 75 micrometer pitch.

Each patterning assembly includes means for applying a coating, a patterning member, and a curing member. Typically, patterning assemblies include patterned rolls and a support structure for holding and driving each roll. Coating means of the first patterning assembly dispenses a first curable coating material on a first surface of the web. Coating means of the second patterning assembly dispenses a second curable coating material on a second surface of the web, wherein the second surface is opposite the first surface. Typically, first and second coating materials are of the same composition. But may be different materials, as desired.

After the first coating material is placed on the web, the web passes over a first patterned member, wherein a pattern is created in the first coating material. The first coating material is then cured or cooled to form the first pattern. Subsequently, after the second coating material is placed on the web, the web passes over a second patterned member, wherein a pattern is created in the second coating material. The second coating material is then cured to form the second pattern. Typically, each patterned member is a microreplicated tool and each tool typically has a dedicated curing member for curing the material. However, it is possible to have a single curing member that cures both first and second patterned materials. Also, it is possible to place the coatings on the patterned tools.

The system also includes means for rotating the first and second patterned rolls such that their patterns are transferred to opposite sides of the web while it is in continuous motion, and said patterns are maintained in continuous registration on said opposite sides of the web to better than about 10 micrometers.

An advantage of the present disclosure is that a web having a microreplicated structure on each opposing surface of the web can be manufactured by having the microreplicated structure on each side of the web continuously formed while keeping the microreplicated structures on the opposing sides registered generally to within 10 micrometers of each other, or within 5 micrometer, or within 3 micrometer, or within 1 micrometer.

Referring now to **FIGS. 5-6**, an example embodiment of a system **110** including a roll to roll casting apparatus **120** is illustrated. In the depicted casting apparatus **120**, a web **122** is provided to the casting apparatus **120** from a main unwind spool (not shown). The exact nature of web **122** can vary widely, depending on the product being produced. However, when the casting apparatus **120** is used for the fabrication of optical articles it is usually convenient for the web **122** to be translucent or transparent, to allow curing through the web **122**. The web **122** is directed around various rollers **126** into the casting apparatus **120**.

Accurate tension control of the web **122** is beneficial in achieving optimal results, so the web **122** may be directed over a tension-sensing device (not shown). In situations where it is desirable to use a liner web to protect the web **122**, the liner web is typically separated at the unwind spool and directed onto a liner web wind-up spool (not shown). The web **122** can be directed via an idler roll to a dancer roller for precision tension control. Idler rollers can direct the web **122** to a position between nip roller **154** and first coating head **156**.

A variety of coating methods may be employed. In the illustrated embodiment, first coating head **156** is a die coating head. The web **122** then passes between the nip roll **154** and first patterned roll **160**. The first patterned roll **160** has a patterned surface **162**, and when the web **122** passes between the nip roller **154** and the first patterned roll **160** the material dispensed onto the web **122** by the first coating head **156** is shaped into a negative of patterned surface **162**.

While the web **122** is in contact with the first patterned roll **160**, material is dispensed from second coating head **164** onto the other surface of web **122**. In parallel with the discussion above with respect to the first coating head **156**, the second coating head **164** is also a die coating arrangement including a second extruder (not shown) and a second coating die (not shown). In some embodiments, the material dispensed by the first coating head **156** is a composition including a polymer precursor and intended to be cured to solid polymer with the application of curing energy such as, for example, ultraviolet radiation.

Material that has been dispensed onto web **122** by the second coating head **164** is then brought into contact with second patterned roll **174** with a second patterned surface **176**. In parallel with the discussion above, in some embodiments, the material dispensed by the second coating head **164** is a composition including a polymer precursor and intended to be cured to solid polymer with the application of curing energy such as, for example, ultraviolet radiation.

At this point, the web **122** has had a pattern applied to both sides. A peel roll **182** may be present to assist in removal of the web **122** from second patterned roll **174**. In some instances, the web tension into and out of the roll to roll casting apparatus is nearly constant.

The web **122** having a two-sided microreplicated pattern is then directed to a wind-up spool (not shown) via various idler rolls. If an interleave film is desired to protect web **122**, it may be provided from a secondary unwind spool (not shown) and the web and interleave film are wound together on the wind-up spool at an appropriate tension.

Referring to **FIGS. 5-7**, first and second patterned rolls are coupled to first and second motor assemblies **210, 220**, respectively. Support for the motor assemblies **210, 220** is accomplished by mounting assemblies to a frame **230**, either directly or indirectly. The motor assemblies **210, 220** are coupled to the frame using precision mounting arrangements. In the example embodiment shown, first motor assembly **210** is fixedly mounted to frame **230**. Second motor assembly **220**, which is placed into position when web **122** is threaded through the casting apparatus **120**, may need to be positioned repeatedly and is therefore movable, both in the cross- and machine direction. Movable motor arrangement **220** may be coupled to linear slides **222** to assist in repeated accurate positioning, for example, when switching between patterns on the rolls. Second motor arrangement **220** also includes a second mounting arrangement **225** on the backside of the frame **230** for positioning the second patterned roll **174** side-to-side relative to the first patterned roll **160**. In some cases, second mounting arrangement **225** includes linear slides **223** allowing accurate positioning in the cross machine directions.

Referring to **FIG. 8**, an example embodiment of a casting apparatus **420** for producing a two-sided web **422** with registered microreplicated structures on opposing surfaces is illustrated. Assembly includes first and second coating means **456, 464**, a nip roller **454**, and first and second patterned rolls **460, 474**. Web **422** is presented to the first coating means **456**, in this example a first extrusion die **456**. First die **456** dispenses a first curable liquid layer coating **470** onto the web **422**. First coating **470** is pressed into the first patterned roller **460** by means of a nip roller **454**, typically a rubber covered roller. While on the first patterned roll **460**, the coating is cured using a curing source **480**, for example, a lamp, of suitable wavelength light, such as, for example, an ultraviolet light source.

A second curable liquid layer **481** is coated on the opposite side of the web **422** using a second side extrusion die **464**. The second layer **481** is pressed into the second patterned tool roller **474** and the curing process repeated for the second coating layer **481**. Registration of the two coating patterns is achieved by maintaining the tool rollers **460, 474** in a precise angular relationship with one another, as will be described hereinafter.

Referring to **FIG. 9**, a close-up view of a portion of first and second patterned rolls **560, 574** is illustrated. First patterned roll **560** has a first pattern **562** for forming a microreplicated surface. Second pattern roll **574** has a second microreplicated pattern **576**. In the example embodiment shown, first and second patterns **562, 576** are the same pattern, though the patterns may be different. In the illustrated embodiment, the first pattern **562** and the second pattern **576** are shown as prism structures, however, any single or multiple useful structures can form the first pattern **562** and the second pattern **576**. In an illustrative embodiment, first pattern **562** can be a cylindrical lens structure and the second pattern **576** can be a prism lens structure, or vice versa.

As a web **522** passes over the first roll **560**, a first curable liquid (not shown) on a first surface **524** is cured by a curing light source **525** near a first region **526** on the first patterned roll **560**. A first microreplicated patterned structure **590** is formed on the first side **524** of the web **522** as the liquid is cured. The first patterned structure **590** is a negative of the pattern **562** on the first patterned roll **560**. After the first patterned structure **590** is formed, a second curable liquid **581** is dispensed onto a second surface **527** of the web **522**. To insure that the second liquid **581** is not cured prematurely, the second liquid **581** can be isolated from the first curing light **525**, by a locating the first curing light **525** so that it does not fall on the second liquid **581**. Alternatively, shielding means **592** can be placed between the first curing light **525** and the second liquid **581**. Also, the curing sources can be located inside their respective patterned rolls where it is impractical or difficult to cure through the web.

After the first patterned structure **590** is formed, the web **522** continues along the first roll **560** until it enters the gap region **575** between the first and second patterned rolls **560, 574**. The second liquid **581** then engages the second pattern **576** on the second patterned roll and is shaped into a second microreplicated structure, which is then cured by a second curing light **535**. As the web **522** passes into the gap **575** between first and second patterned rolls **560, 574**, the first patterned structured **590**, which is by this time substantially cured and bonded to the web **522**, restrains the web **522** from slipping while the web **522** begins moving into the gap **575** and around the second patterned roller **574**. This removes web stretching and slippages as a source of registration error between the first and second patterned structures formed on the web.

By supporting the web **522** on the first patterned roll **560** while the second liquid **581** comes into contact with the second patterned roll **574**, the degree of registration between the first and second microreplicated structures **590, 593** formed on opposite sides **524, 527** of the web **522** becomes a function of controlling the positional relationship between the surfaces of the first and second patterned rolls **560, 574**. The S-wrap of the web around the first and second patterned rolls **560, 574** and between the gap **575** formed by the rolls minimizes effects of tension, web strain changes, temperature, microslip caused by mechanics of nipping a web, and lateral position control. Typically, the S-wrap maintains the web **522** in contact with each roll over a wrap angle of 180 degrees, though the wrap angle can be more or less depending on the particular requirements.

To increase the degree of registration between the patterns formed on opposite surfaces of a web, it preferred to have a low-frequency pitch variation around the mean diameter of each roll. Typically, the patterned rolls are of the same mean diameter, though this is not required. It is within the skill and knowledge of one having ordinary skill in the art to select the proper roll for any particular application.

Referring to **FIG. 10**, a motor mounting arrangement is illustrated. A motor **633** for driving a tool or patterned roll **662** is mounted to the machine frame **650** and connected through a coupling **640** to a rotating shaft **601** of the patterned roller **662**. The motor **633** is coupled to a primary encoder **630**. A secondary encoder **651** is coupled to the tool to provide precise angular registration control of the patterned roll **662**. Primary **630** and secondary **651** encoders cooperate to provide control of the patterned roll **662** to keep it in registration with a second patterned roll, as will be described further hereinafter.

Reduction or elimination of shaft resonance is important as this is a source of registration error allowing pattern position control within the specified limits. Using a coupling **640** between the motor **633** and shaft **650** that is larger than general sizing schedules specify will also reduce shaft resonance caused by more flexible couplings. Bearing assemblies **660** are located in various locations to provide rotational support for the motor arrangement.

In the example embodiment shown, the tool roller **662** diameter can be smaller than its motor **633** diameter. To accommodate this arrangement, tool rollers may be installed in pairs arranged in mirror image. In **FIG. 11** two tool rollers assemblies **610** and **710** are installed as mirror images in order to be able to bring the two tool rollers **662** and **762** together. Referring also to **FIG. 3**, the first motor arrangement is typically fixedly attached to the frame and the second motor arrangement is positioned using movable optical quality linear slides.

Tool roller assembly **710** is quite similar to tool roller assembly **610**, and includes a motor **733** for driving a tool or patterned roll **762** is mounted to the machine frame **750** and connected through a coupling **740** to a rotating shaft **701** of the patterned roller **762**. The motor **733** is coupled to a primary encoder **730**. A secondary encoder **751** is coupled to the tool to provide precise angular registration control of the patterned roll **762**. Primary **730** and secondary **751** encoders cooperate to provide control of the patterned roll **762** to keep it in registration with a second patterned roll, as will be described further hereinafter.

Reduction or elimination of shaft resonance is important as this is a source of registration error allowing pattern position control within the specified limits. Using a coupling **740** between the motor **733** and shaft **750** that is larger than general sizing schedules specify will also reduce shaft resonance caused by more flexible couplings. Bearing assemblies **760** are located in various locations to provide rotational support for the motor arrangement.

Because the feature sizes on the microreplicated structures on both surfaces of a web are desired to be within fine registration of one another, the patterned rolls should be controlled with a high degree of precision. Cross-web registration within the limits described herein can be accomplished by applying the techniques used in controlling machine-direction registration, as described hereinafter. For example, to achieve about 10 micrometers end-to-end feature placement on a 10-inch circumference patterned roller, each roller must be maintained within a rotational accuracy of ± 32 arc-seconds per revolution. Control of registration becomes more difficult as the speed the web travels through the system is increased.

Applicants have built and demonstrated a system having 10-inch circular patterned rolls that can create a web having patterned features on opposite surfaces of the web that are registered to within 2.5 micrometers. Upon reading this disclosure and applying the principles taught herein, one of ordinary skill in the art will appreciate how to accomplish the degree of registration for other microreplicated surfaces.

Referring to **FIG. 12**, a schematic of a motor arrangement **800** is illustrated. Motor arrangement **800** includes a motor **810** including a primary encoder **830** and a drive shaft

820. Drive shaft **820** is coupled to a driven shaft **840** of patterned roll **860** through a coupling **825**. A secondary, or load, encoder **850** is coupled to the driven shaft **840**. Using two encoders in the motor arrangement described allows the position of the patterned roll to be measured more accurately by locating the measuring device (encoder) **850** near the patterned roll **860**, thus reducing or eliminating effects of torque disturbances when the motor arrangement **800** is operating.

Referring to **FIG. 13**, a schematic of the motor arrangement of **FIG. 12**, is illustrated as attached to control components. In the example apparatus shown in **FIGS. 5-7**, a similar set-up would control each motor arrangement **210** and **220**. Accordingly, motor arrangement **900** includes a motor **910** including a primary encoder **930** and a drive shaft **920**. Drive shaft **920** is coupled to a driven shaft **940** of patterned roll **960** through a coupling **930**. A secondary, or load, encoder **950** is coupled to the driven shaft **940**.

Motor arrangement **900** communicates with a control arrangement **965** to allow precision control of the patterned roll **960**. Control arrangement **965** includes a drive module **966** and a program module **975**. The program module **975** communicates with the drive module **966** via a line **977**, for example, a SERCOS fiber network. The program module **975** is used to input parameters, such as set points, to the drive module **966**. Drive module **966** receives input 480 volt, 3-phase power **915**, rectifies it to DC, and distributes it via a power connection **973** to control the motor **910**. Motor encoder **912** feeds a position signal to control module **966**. The secondary encoder **950** on the patterned roll **960** also feeds a position signal back to the drive module **966** via to line **971**. The drive module **966** uses the encoder signals to precisely position the patterned roll **960**. The control design to achieve the degree of registration is described in detail below.

In the illustrative embodiments shown, each patterned roll is controlled by a dedicated control arrangement. Dedicated control arrangements cooperate to control the registration between first and second patterned rolls. Each drive module communicates with and controls its respective motor assembly.

The control arrangement in the system built and demonstrated by Applicants include the following. To drive each of the patterned rolls, a high performance, low cogging torque motor with a high-resolution sine encoder feedback (512 sine cycles x 4096 drive interpolation >> 2 million parts per revolution) was used, model MHD090B-

035-NG0-UN, available from Bosch-Rexroth (Indramat). Also the system included synchronous motors, model MHD090B-035-NG0-UN, available from Bosch-Rexroth (Indramat), but other types, such as induction motors could also be used.

Each motor was directly coupled (without gearbox or mechanical reduction) through an extremely stiff bellows coupling, model BK5-300, available from R/W Corporation. Alternate coupling designs could be used, but bellows style generally combines stiffness while providing high rotational accuracy. Each coupling was sized so that a substantially larger coupling was selected than what the typical manufacturers specifications would recommend.

Additionally, zero backlash collets or compressive style locking hubs between coupling and shafts are preferred. Each roller shaft was attached to an encoder through a hollow shaft load side encoder, model RON255C, available from Heidenhain Corp., Schaumburg, IL. Encoder selection should have the highest accuracy and resolution possible, typically greater than 32 arc-sec accuracy. Applicants' design, 18000 sine cycles per revolution were employed, which in conjunction with the 4096 bit resolution drive interpolation resulted in excess of 50 million parts per revolution resolution giving a resolution substantially higher than accuracy. The load side encoder had an accuracy of +/- 2 arc-sec; maximum deviation in the delivered units was less than +/- 1 arc-sec.

In some instances, each shaft may be designed to be as large a diameter as possible and as short as possible to maximize stiffness, resulting in the highest possible resonant frequency. Precision alignment of all rotational components is desired to ensure minimum registration error due to this source of registration error.

Referring to **FIG. 14,** in Applicants' system identical position reference commands were presented to each axis simultaneously through a SERCOS fiber network at a 2 ms update rate. Each axis interpolates the position reference with a cubic spline, at the position loop update rate of 250 microsecond intervals. The interpolation method is not critical, as the constant velocity results in a simple constant times time interval path. The resolution is critical to eliminate any round off or numerical representation errors. Axis rollover must also addressed. In some cases, it is important that each axis' control cycle is synchronized at the current loop execution rate (62 microsecond intervals).

The top path **1151** is the feed forward section of control. The control strategy includes a position loop **1110**, a velocity loop **1120**, and a current loop **1130**. The position reference **1111** is differentiated, once to generate the velocity feed forward terms **1152** and a second time to generate the acceleration feed forward term **1155**. The feed forward path **1151** helps performance during line speed changes and dynamic correction.

The position command **1111** is subtracted from current position **1114**, generating an error signal **1116**. The error **1116** is applied to a proportional controller **1115**, generating the velocity command reference **1117**. The velocity feedback **1167** is subtracted from the command **1117** to generate the velocity error signal **1123**, which is then applied to a PID controller. The velocity feedback **1167** is generated by differentiating the motor encoder position signal **1126**. Due to differentiation and numerical resolution limits, a low pass Butterworth filter **1124** is applied to remove high frequency noise components from the error signal **1123**. A narrow stop band (notch) filter **1129** is applied at the center of the motor – roller resonant frequency. This allows substantially higher gains to be applied to the velocity controller **1120**. Increased resolution of the motor encoder also would improve performance. The exact location of the filters in the control diagram is not critical; either the forward or reverse path are acceptable, although tuning parameters are dependent on the location.

A PID controller could also be used in the position loop, but the additional phase lag of the integrator makes stabilization more difficult. The current loop is a traditional PI controller; gains are established by the motor parameters. The highest bandwidth current loop possible will allow optimum performance. Also, minimum torque ripple is desired.

Minimization of external disturbances is important to obtain maximum registration. This includes motor construction and current loop commutation as previously discussed, but minimizing mechanical disturbances is also important. Examples include extremely smooth tension control in entering and exiting web span, uniform bearing and seal drag, minimizing tension upsets from web peel off from the roller, uniform rubber nip roller. In the current design, a third axis geared to the tool rolls is provided as a pull roll to assist in removing the cured structure from the tool.

The web material can be any suitable material on which a microreplicated patterned structure can be created. Examples of web materials are polyethylene terephthalate, polymethyl methacrylate, or polycarbonate. The web can also be multi-layered. Since the liquid is typically cured by a curing source on the side opposite that on which the patterned structure is created, the web material must be at least partially translucent to the curing source used. Examples of curing energy sources are infrared radiation, ultraviolet radiation, visible light radiation, microwave, or e-beam. One of ordinary skill in the art will appreciate that other curing sources can be used, and selection of a particular web material/curing source combination will depend on the particular article (having microreplicated structures in registration) to be created.

An alternative to curing the liquid through the web would be to use a two part reactive cure, for example, an epoxy, which would be useful for webs that are difficult to cure through, such as metal web or webs having a metallic layer. Curing could be accomplished by in-line mixing of components or spraying catalyst on a portion of the patterned roll, which would cure the liquid to form the microreplicated structure when the coating and catalyst come into contact.

The liquid from which the microreplicated structures are created can be a curable photopolymerizable material, such as acrylates curable by UV light. One of ordinary skill in the art will appreciate that other coating materials can be used, and selection of a material will depend on the particular characteristics desired for the microreplicated structures. Similarly, the particular curing method employed is within the skill and knowledge of one of ordinary skill in the art. Examples of curing methods are reactive curing, thermal curing, or radiation curing.

Examples of coating means that useful for delivering and controlling liquid to the web are, for example, die or knife coating, coupled with any suitable pump such as a syringe or peristaltic pump. One of ordinary skill in the art will appreciate that other coating means can be used, and selection of a particular means will depend on the particular characteristics of the liquid to be delivered to the web.

Various modifications and alterations of the present disclosure will be apparent to those skilled in the art without departing from the scope and spirit of this disclosure, and it should be understood that this disclosure is not limited to the illustrative embodiments set forth herein.

What is claimed is:

1. A microreplicated article comprising:

a flexible substrate having first and second opposed surfaces;

a first coated microreplicated pattern on the first surface; and

a second coated microreplicated pattern on the second surface;

wherein, the first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 10 micrometers in the machine direction and transverse direction and the first coated microreplicated pattern and second coated microreplicated pattern form a plurality of lens segments, each lens segment comprises a plurality of lens elements, each lens element having an optical axis where all of the lens element optical axes are parallel to each other and lens elements within a first lens segment have optical axes that are offset from optical axes of lens elements within an adjacent second lens segment.

2. The microreplicated article of claim 1, wherein each lens element has two sides parallel to the machine direction and two sides parallel to the transverse direction, and the first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 5 micrometers on the two sides parallel to the machine direction and the two sides parallel to the transverse direction, of each lens element.

3. The microreplicated article of claims 1 or 2, wherein the first coated microreplicated pattern comprises a plurality of prisms and the second coated microreplicated pattern comprises a plurality of cylindrical lenses.

4. The microreplicated article of claims 1 to 3, wherein the microreplicated article has a total height in a range of 75 to 400 micrometers.

5. The microreplicated article of claims 1 to 4, wherein the first coated microreplicated pattern and the second coated microreplicated pattern have a repeating period in a range of 50 to 150 micrometers.

6. The microreplicated article of claims 1 to 5, wherein the adjacent lens segments lens element optical axis are offset from each other by 20 micrometers or less.

7. The microreplicated article of claims 1 to 6, wherein the each lens segment has a length in a range of 250 to 2000 micrometers.

8. The microreplicated article of claims 1 to 7, wherein the adjacent lens segments lens element optical axis are offset from each other by a random distance selected from a predetermined distance range.

9. The microreplicated article of claims 1 to 8, wherein the adjacent lens segments lens element optical axis are offset from each other by a constant distance.

10. A method of making a microreplicated article including a plurality of microreplicated lens features, the method comprising:

providing a substrate, in web form, having first and second opposed surfaces; and

passing the substrate through a roll to roll casting apparatus to form a first coated microreplicated pattern on the first surface and a second coated microreplicated pattern on the second surface;

wherein, the first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 10 micrometers in the machine direction and transverse direction and the first coated microreplicated pattern and second coated microreplicated pattern form a plurality of lens segments, each lens segment comprise a plurality of lens elements, each lens element having an optical axis where all of the lens element optical axes are parallel to each other and lens elements within a first lens segment have optical axes that are offset from optical axes of lens elements within an adjacent second lens segment.

11. The method of claim 10, wherein the passing step comprises passing the substrate through a roll to roll casting apparatus to form a first coated microreplicated pattern on the

first surface and a second coated microreplicated pattern on the second surface, and the first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 10 micrometers in the machine direction and transverse direction and the first coated microreplicated pattern and second coated microreplicated pattern form a plurality of lens segments, each lens segment comprise a plurality of lens elements, each lens element having an optical axis where all of the lens element optical axis are parallel to each other and lens elements within a first lens segment have optical axes that are offset by 20 micrometers or less from optical axes of lens elements within an adjacent second lens segment.

12. The method of claims 10 or 11, wherein the passing step comprises passing the substrate through a roll to roll casting apparatus to form a first coated microreplicated pattern on the first surface and a second coated microreplicated pattern on the second surface, and the first coated microreplicated pattern comprises a plurality of prisms and the second coated microreplicated pattern comprises a plurality of cylindrical lenses.

13. The method of claims 10 to 12, wherein the passing step comprises passing the substrate through a roll to roll casting apparatus to form a first coated microreplicated pattern on the first surface and a second coated microreplicated pattern on the second surface, wherein the first coated microreplicated pattern and the second coated microreplicated pattern have a repeating period in a range of 50 to 150 micrometers.

14. An optical display comprising:

a light source;

an optical film comprising:

a flexible substrate having first and second opposed surfaces;

a first coated microreplicated pattern on the first surface; and

a second coated microreplicated pattern on the second surface, wherein the first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 10 micrometers in the machine direction and transverse direction and the first coated microreplicated pattern and second coated microreplicated pattern form a plurality of lens segments, each lens segment comprise a plurality of lens elements, each lens element having an optical axis where all of the lens element optical axes are parallel to each other and lens elements within a first lens segment have optical axes that are offset from optical axes of lens elements within an adjacent second lens segment; and

an optical component having a surface opposing the optical film, wherein light from the light source passes through the optical film and the optical component.

15. The optical display of claim 14, wherein the optical component comprises a liquid crystal display cell disposed to receive the light from the optical film.

16. The optical display of claim 15, wherein the liquid crystal display cell comprises a plurality of pixel columns parallel with each lens element optical axis.

17. The optical display of claims 14 to 16, wherein each lens element has two sides parallel to the machine direction and two sides parallel to the transverse direction, and the first coated microreplicated pattern and the second coated microreplicated pattern are registered to within 5 micrometers on the two sides parallel to the machine direction and the two sides parallel to the transverse direction, of each lens element.

18. The optical display of claims 14 to 17, wherein the first coated microreplicated pattern comprises a plurality of prisms and the second coated microreplicated pattern comprises a plurality of cylindrical lenses.

19. The optical display of claims 14 to 18, wherein the microreplicated article has a total height in a range of 75 to 400 micrometers.

20. The optical display of claims 14 to 19, wherein the first coated microreplicated pattern and the second coated microreplicated pattern have a repeating period in a range of 50 to 150 micrometers.

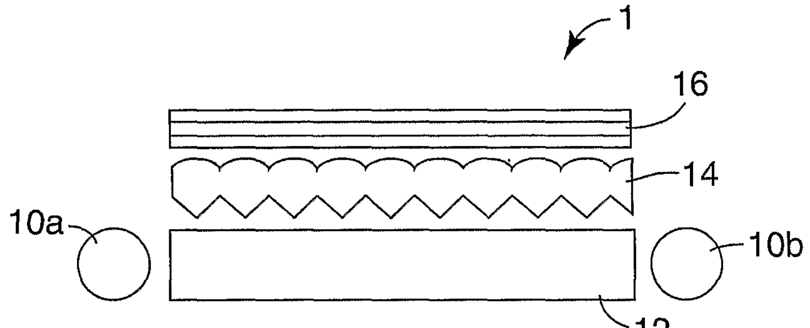

Fig. 1

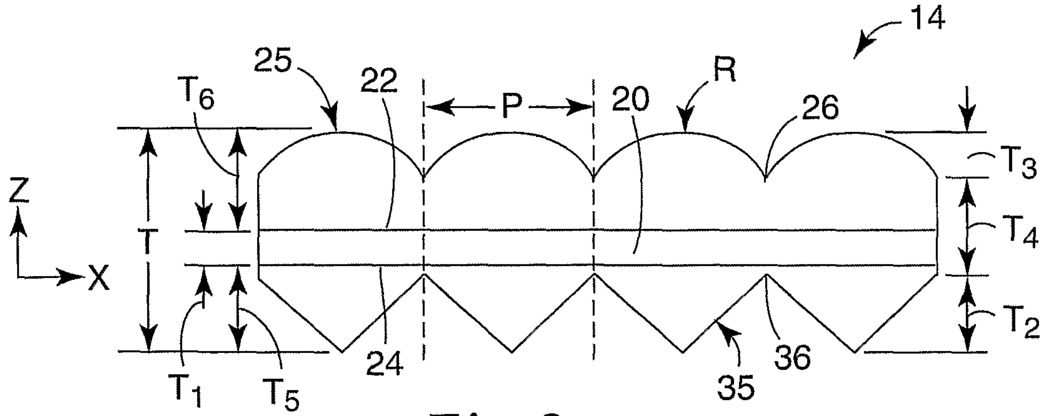

Fig. 2

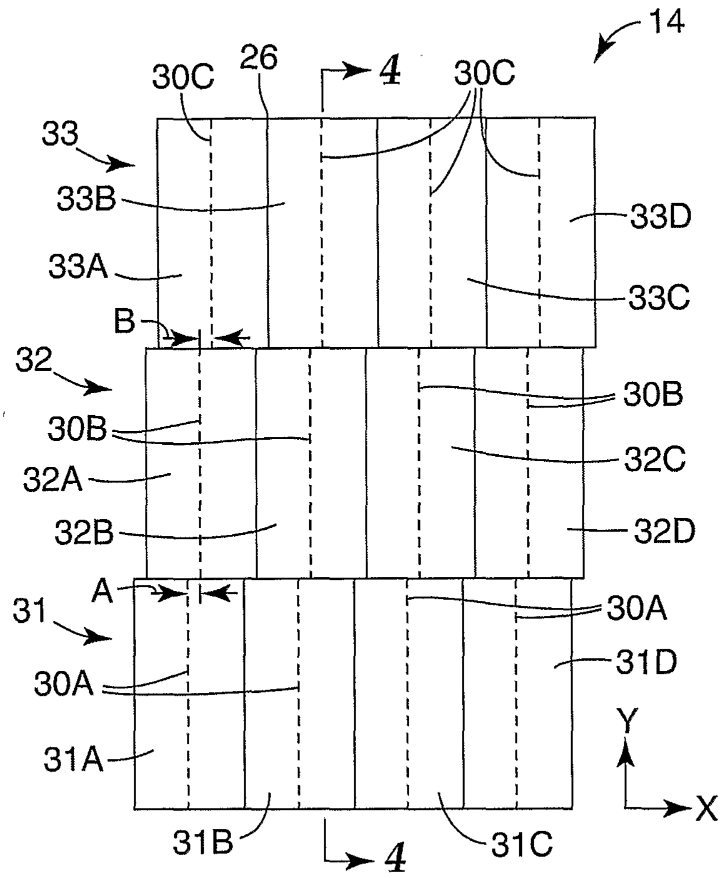
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Fig. 3

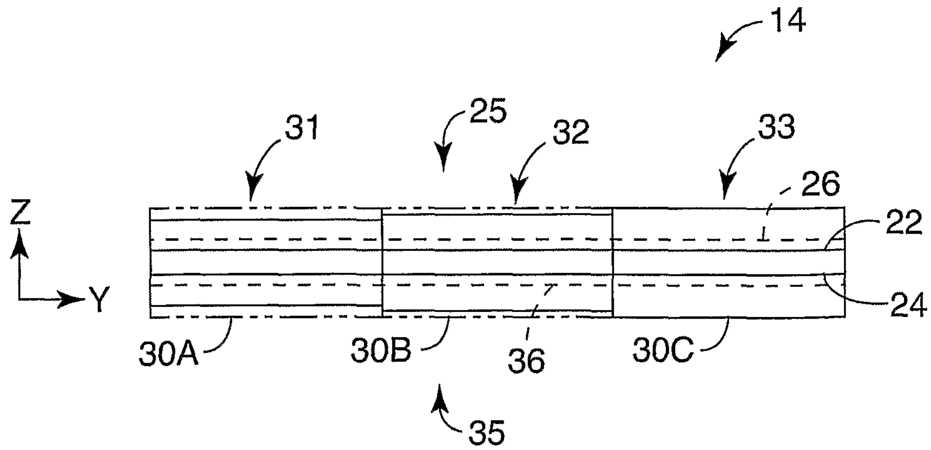
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Fig. 4

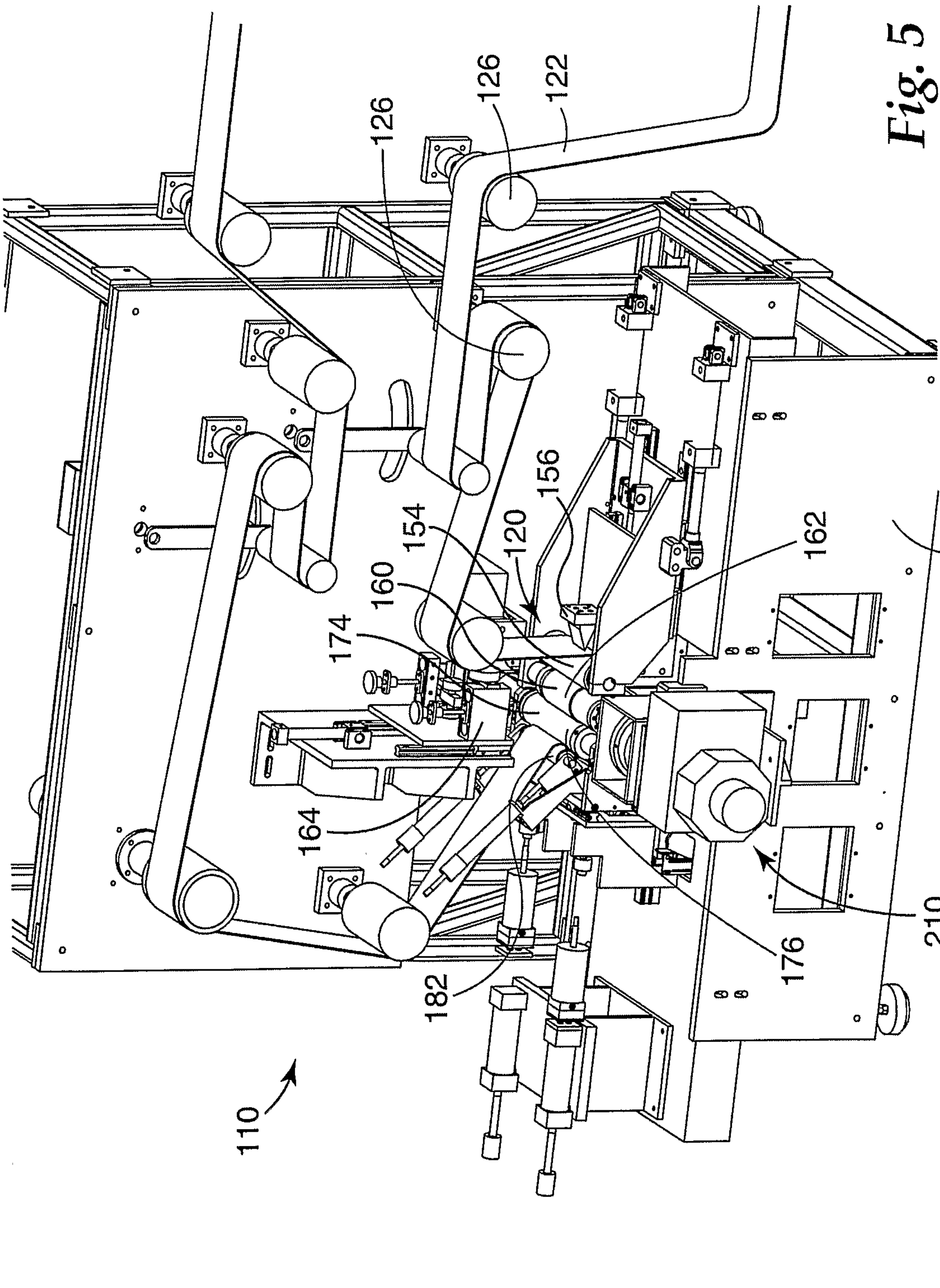

Fig. 5

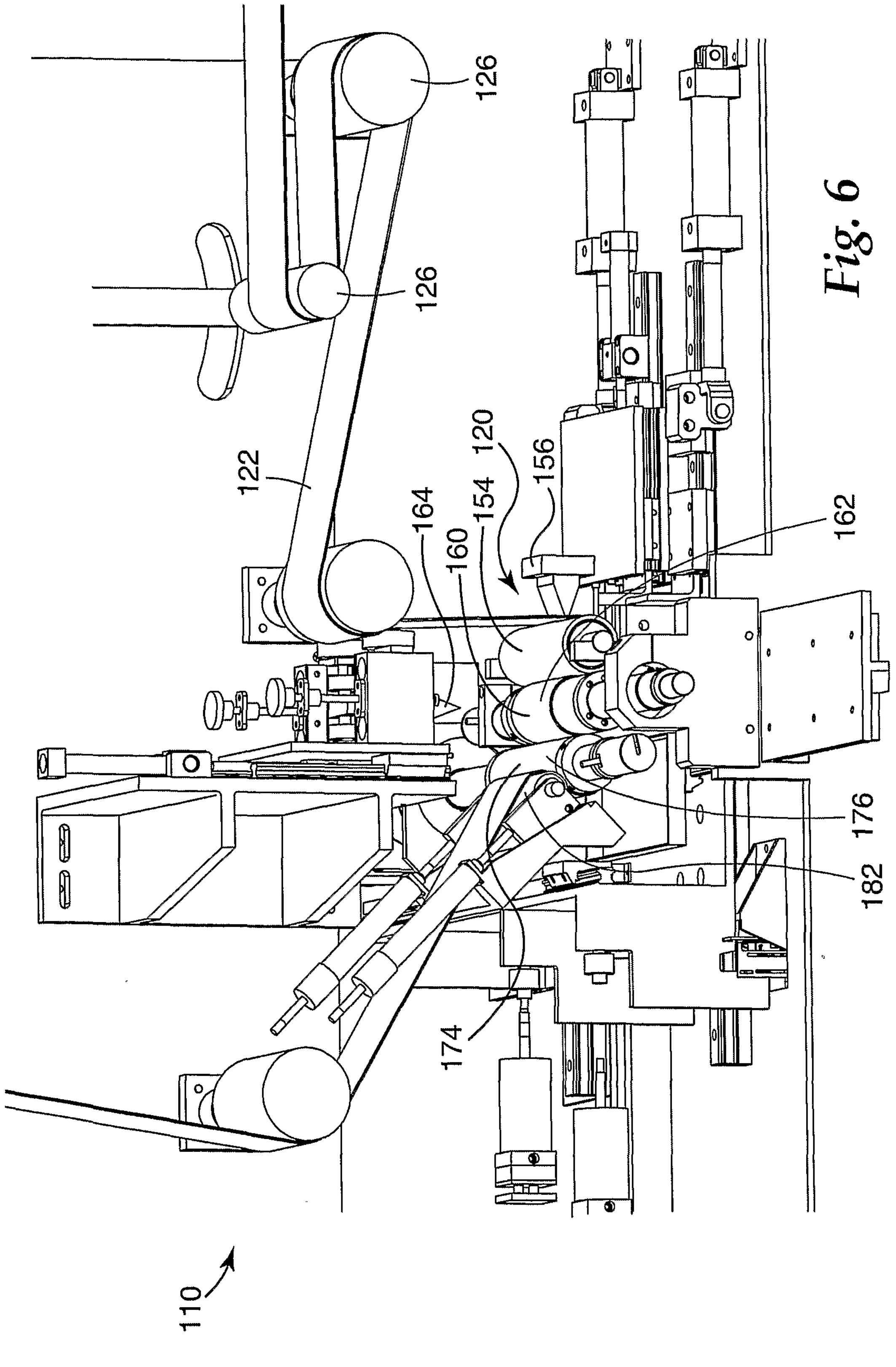

Fig. 6

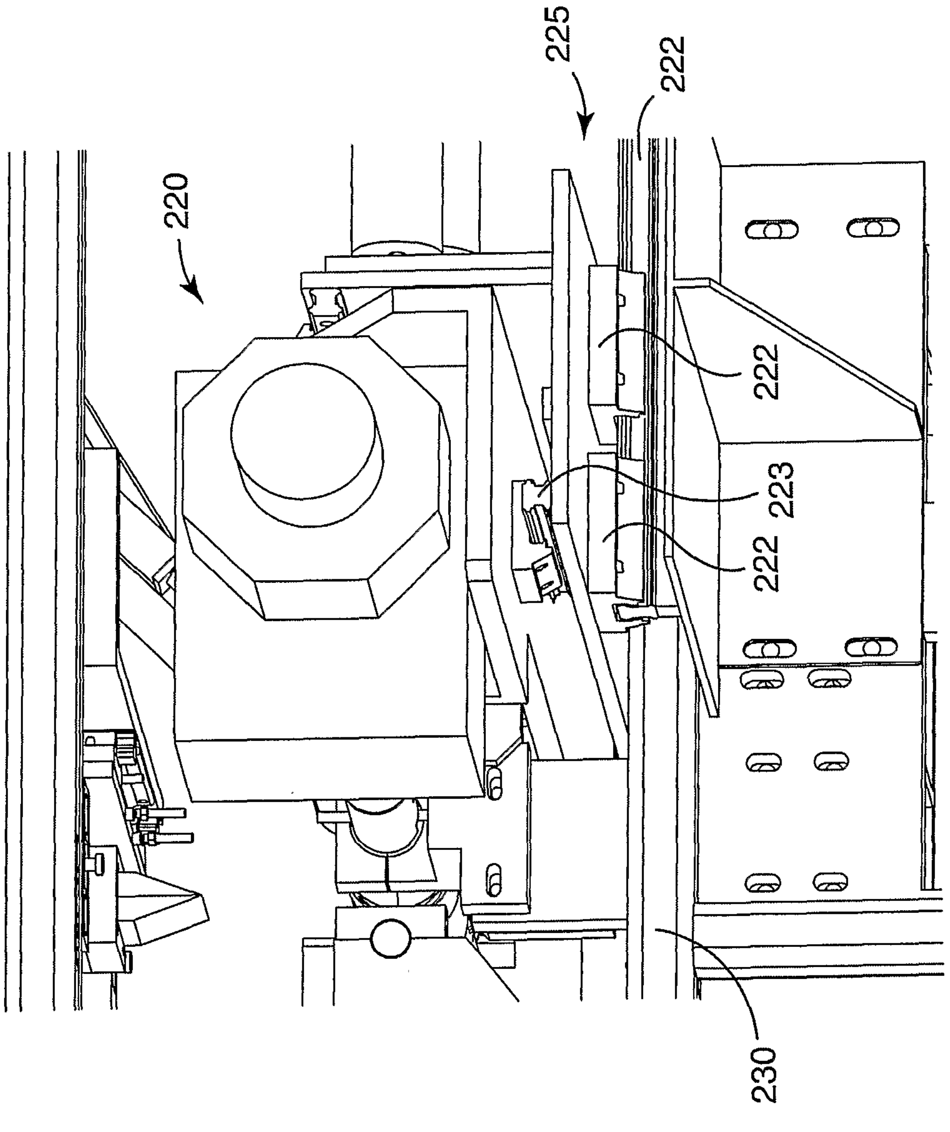

Fig. 7

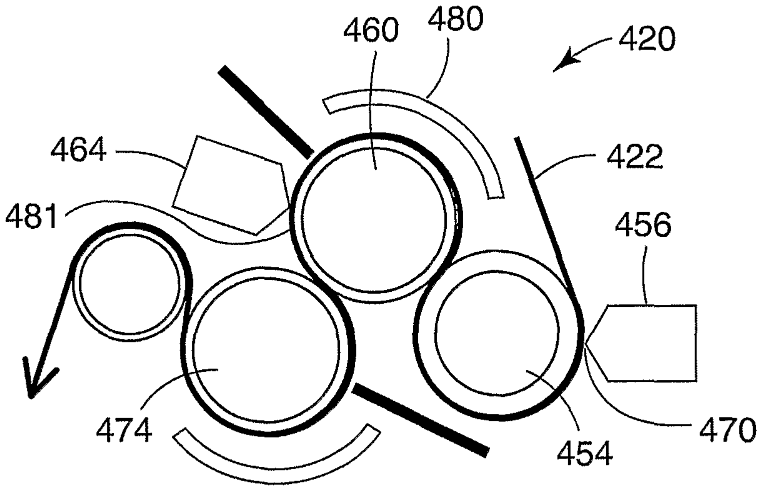
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Fig. 8

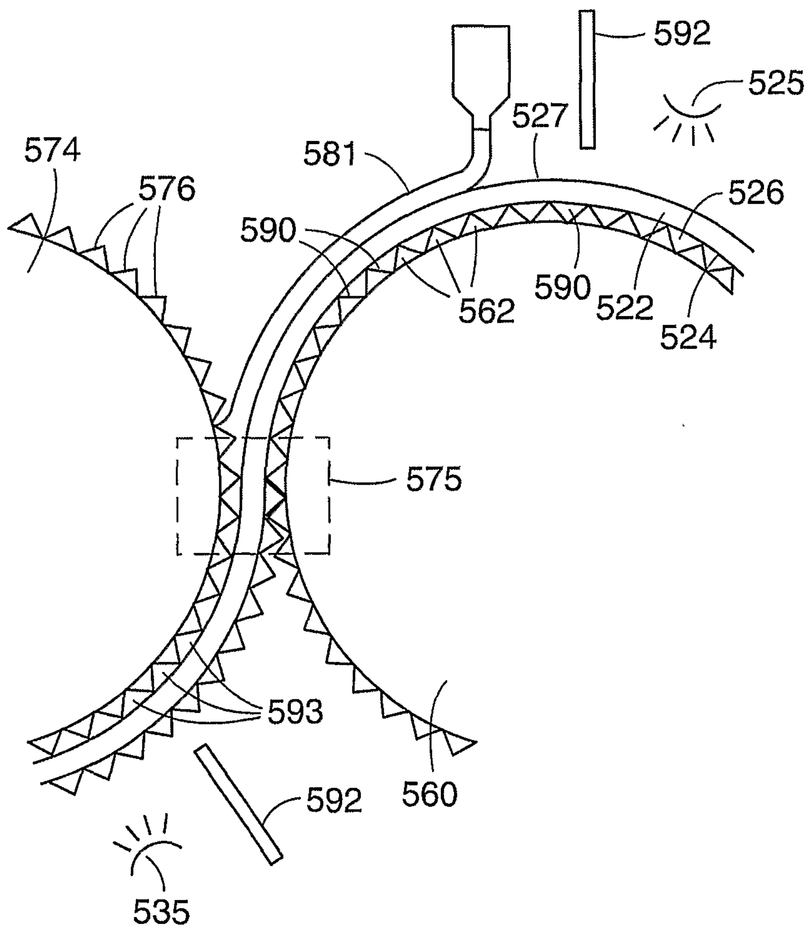
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Fig. 9

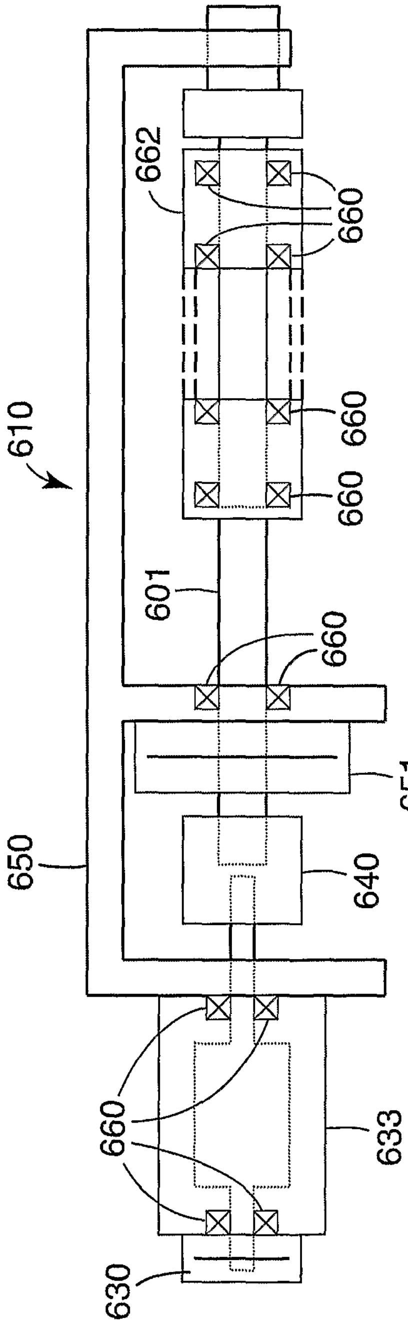
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Fig. 10

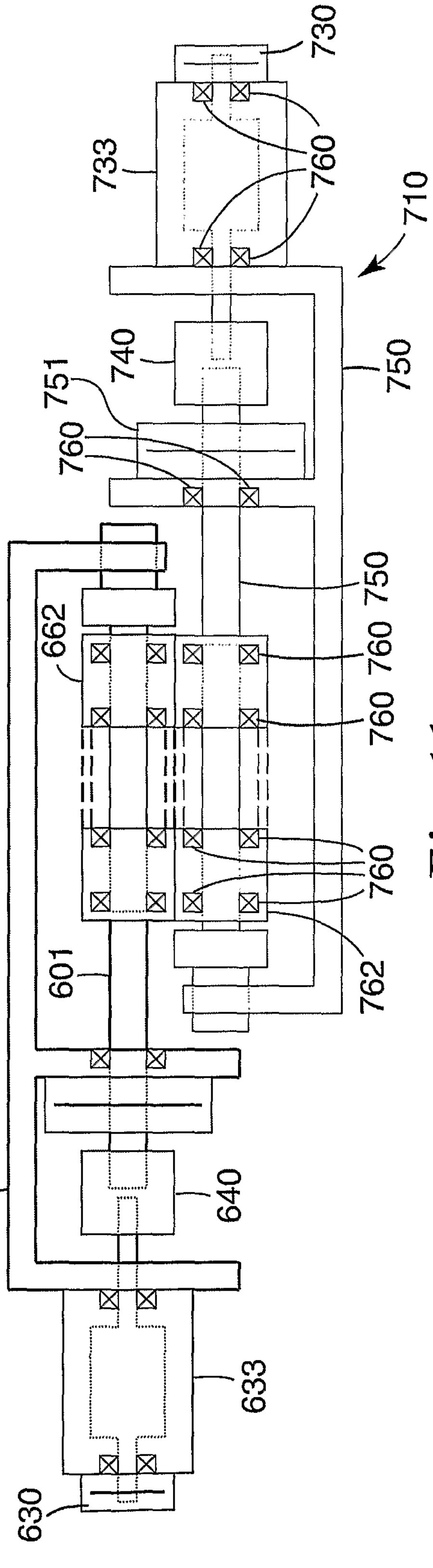
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Fig. 11

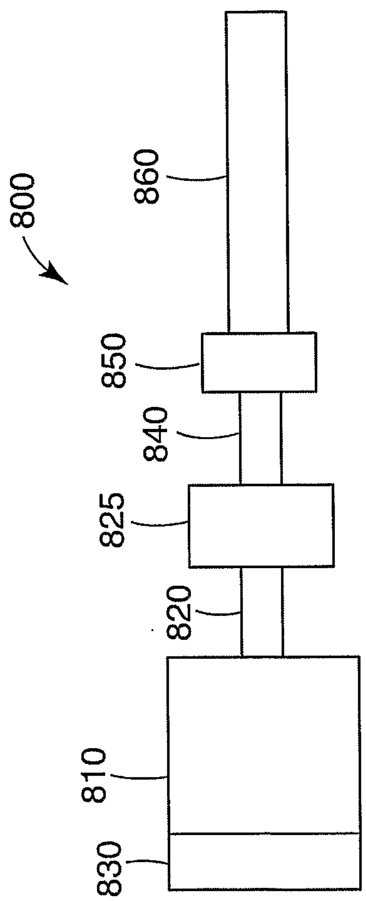


Fig. 12

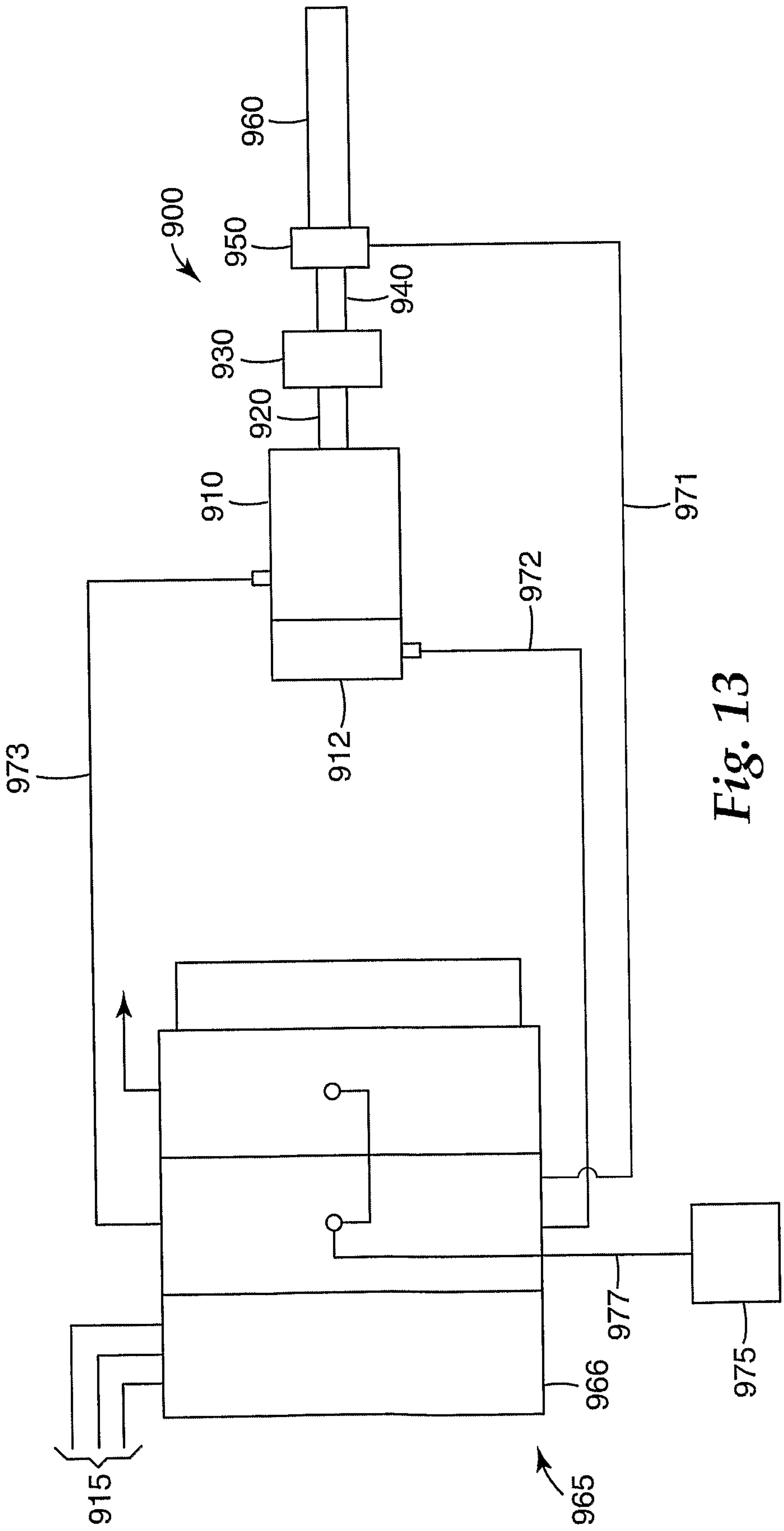
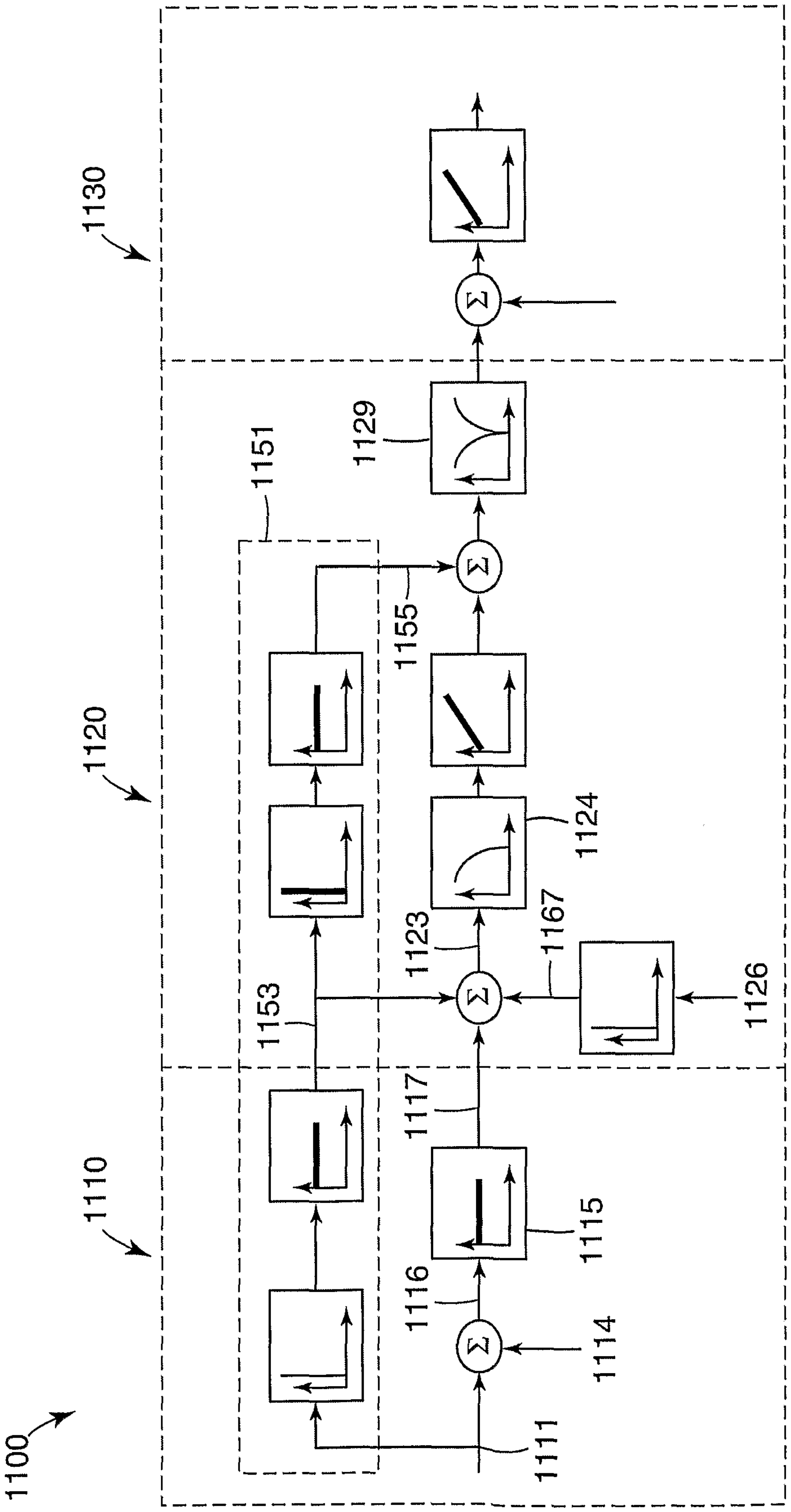


Fig. 13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1167
Σ

Fig. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/007977

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B3/00 G02B5/04 B29D11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B B29D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 12, 5 December 2003 (2003-12-05) & JP 2005 007873 A (DAINIPPON PRINTING CO LTD), 13 January 2005 (2005-01-13) abstract -& WO 2004/103683 A (DAI NIPPON PRINTING CO., LTD; HONDA, MAKOTO) 2 December 2004 (2004-12-02)	1-20
L	-& US 2006/062969 A1 (HONDA MAKOTO) 23 March 2006 (2006-03-23) paragraph [0010] - paragraph [0023] figures	
P,X	US 2005/224997 A1 (LIAO TSUNG-NENG ET AL) 13 October 2005 (2005-10-13) abstract; figures	1-20

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* *Special categories of cited documents :*

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 July 2006	25/07/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Seibert, J

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/007977

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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