

RING LIGHT ILLUMINATOR AND BEAM SHAPER FOR RING LIGHT ILLUMINATOR

CROSS REFERENCE TO RELATED APPLICATIONS

[001] This patent application claims priority of US provisional patent application No. 61/328,869 filed April 28, 2010, the application is incorporated herein by reference.

FIELD OF THE INVENTION

[002] The present invention relates to a ring light illuminator.

[003] The present invention also relates to a beam shaper.

BACKGROUND OF THE INVENTION

[004] In many optical inspection or imaging tasks a well-defined illumination of the area to be inspected or imaged is required. For many such illumination purposes ring lights are used, for example in microscopy, where they are a common means to provide a dark field illumination. In such applications, it is desirable to restrict the area illuminated to the area of interest, and to have a homogeneous distribution of light within the area of interest. Possible light sources for example are arc lamps, LEDs (light emitting diodes), laser diodes, and halogen bulbs. While arc lamps typically provide higher light intensities than LEDs, they also exhibit stronger intensity fluctuations and shorter life times than LEDs; thus generally LEDs are a preferred choice of light source. As light from typical LEDs is emitted into a hemisphere around the LED, optical elements are required to direct as much as possible of the emitted light from one or plural LEDs into the area of interest, i.e. into the area to be illuminated.

[005] The European Patent Application EP 1 919 001 A1 relates to a spot light device for product inspection, wherein a LED is used as light source. In order to homogenize the distribution of light across a certain area, the light from the LED is passed through a rod lens. The light from the LED is introduced into the rod lens by a condensing lens. In order to assure proper alignment of rod lens and condensing lens, and also in order to reduce the number of individual parts to be handled during assembly of an optical system, the rod lens and condensing lens are provided as sections of an optical unit, the rod lens constituting a light transmitting section and the condensing lens a light condensing section. The condensing

section combines refraction and reflection in order to direct light from the light source into the transmitting section.

[006] The European Patent Application EP 2 177 816 A2 discloses an array of light sources, in particular LEDs, the light of which is directed into a light integrator shaped as a rod. The light integrator homogenizes and constrains the light, based on reflection of the light within the integrator. The light integrator may be a hollow tube with reflective inner surface or a solid rod of an optically transparent material, where the reflection of light within the light integrator is due to total internal reflection. The cross-section of the light integrator may be circular, polygonal, or irregular. Further optical elements may be provided downstream from the light integrator. To each of the light sources there may correspond an optical element for controlling and directing the light from the light source. The light integrator may be tapered, in order to influence the divergence of the light exiting from the light integrator.

[007] The European Patent Application EP 1 150 154 A1 discloses an illumination system, in particular for microscopes, wherein plural light sources, preferentially LEDs, are arranged in an annular carrier. The LEDs may be controlled individually or in groups, and exhibit a small angle of emission.

[008] The German Patent Application DE 28 52 203 discloses an illumination setup for a microscope, where light from a light source is guided along optical fibres and exits the fibres at a respective end of the fibres, wherein these respective ends are arranged in an annular fashion. A further ring illumination system, based on optical fibres is for example disclosed in the German patent application DE 40 16 264.

[010] A problem of ring illumination systems based on optical fibres is the large divergence of the light exiting an optical fibre. Likewise, annular arrangements of LEDs tend to create rather inhomogeneous illumination fields, and even if such LEDs are used in combination with state of the art collector lenses, the degree of homogeneity of the illumination field required for some applications is not achievable.

[011] Maximum light intensity is a very important design parameter for ring lights, as these inherently are “dark field” illumination, where scattered light is often a viewing object. A main disadvantage of LEDs compared to arc lamps (a standard for bright illumination for normal microscope viewing), is that they are typically dimmer. It is often the case, that LED based systems do not provide adequate light intensity at the viewed object, and that extreme

care in design should be made to maximize the possible light at the image. Maximizing the light is particularly important in machine vision/ inspection where integration time cannot be arbitrarily lengthened to increase the light energy available to create a well exposed image. Increase of the integration time in a machine vision system decreases the frequency of images and increases the total inspection time (image time). Since the value of an inspection machine depends on how many fields can be imaged in a fixed time, maximizing the light at the object is a very important feature.

SUMMARY OF THE INVENTION

[012] It is an object of the present invention to provide a ring light illuminator capable of creating a well-defined and homogeneous illumination field in an area to be illuminated. Additionally, light from ring illuminator should be collected efficiently and directed to the area to be illuminated.

[013] This object is achieved by a ring light illuminator with a plurality of light sources, wherein to each light source there corresponds a beam shaper, the beam shaper comprising:

- a light collector for collecting light from a light source;
- a homogenizing means for light from the light source; and
- an imaging means for imaging an output of the homogenizing means into an area to be illuminated.

[014] It is a further object of the invention to provide a beam shaper which is easily mounted and does not require alignment of its parts. Additionally, light from a light source should be collected efficiently and minimal truncation losses of an imaging lens should result.

[015] This object is achieved by a beam shaper manufactured as one piece, comprising:

- a light collector for collecting light from a light source;
- a homogenizing rod for homogenizing the light from the light source; and
- a lens for imaging an end of the homogenizing rod opposite the light collector into an area to be illuminated.

[016] The ring light illuminator according to the invention comprises a plurality of light sources arranged in an annular fashion. In preferred embodiments each light source is a light

emitting diode (LED) or an array of LEDs. According to the invention, to each light source there corresponds a beam shaper. The beam shaper receives light from the light source and directs it into an area to be illuminated in such a way that an illumination field is created in the area to be illuminated, wherein the illumination field is of a well-defined shape and the illumination across the illumination field is homogeneous to a degree sufficient for the inspection or illumination task at hand.

[017] The beam shaper comprises a light collector, a homogenizing means, and an imaging means.

[018] The purpose of the light collector is to receive light from the light source and to direct it to the homogenizing means. The light collector preferentially is designed in such a way that an as large as possible fraction of the light emitted by the light source is collected by it and directed onto the homogenizing means, so that eventually an illumination field of sufficient intensity is achievable in the area to be illuminated.

[019] The purpose of the homogenizing means is to reduce inhomogeneities of light intensity across the light beam, so that eventually the intensity of light across the illumination field is homogeneous to a sufficiently high degree.

[020] The purpose of the imaging means is to image the output of the homogenizing means into the area to be illuminated. The size of the illumination field in part depends on the imaging properties of the imaging means.

[021] In one preferred embodiment the homogenizing means is a rod of circular, elliptical, rectangular, square, hexagonal, octagonal or other cross-section; the cross-section herein is perpendicular to an optical axis of the beam shaper. The rod has a first end, through which light is received from the light collector, and a second end, opposite the first end along the optical axis, by which the light exits the rod. The second end of the rod is imaged into the area to be illuminated by the imaging means. The shape of the illumination field created in this way is determined by the cross section of the rod. The homogenizing function of the rod is due to reflection, typically multiple reflection, of light from the sides of the rod parallel to the optical axis. Preferentially, the rod is a solid piece of matter, transparent at least for the wavelengths of light to be used for illumination, and the reflection is total internal reflection. Alternatively, the sides of the rod can be provided with a reflective coating, or the rod can be a hollow tube with reflective inner walls. A benefit of the invention is that it combines

collection efficiency of TIR lens and minimal truncation losses of the imaging lens of the beam shaper.

[022] Advantageously, the rod and the light collector form an integral unit, and in particular may be manufactured as one piece. This reduces the number of individual parts which need to be handled in assembly or maintenance of the ring light illuminator, and also obviates the need to properly align the light collector and the rod during assembly or maintenance. Even more advantageously, light collector, rod, and imaging means form an integral unit and may be manufactured as one piece.

[023] In some embodiments the imaging means is a lens.

[024] In alternative embodiments, the homogenizing means is a texture provided on the light collector.

[025] As the operation of the light sources generates heat, advantageously a cooling mechanism for the ring light illuminator is provided. In embodiments, this cooling mechanism comprises cooling fins provided on the outer surface of the ring light illuminator, so that the surface for heat exchange with the environment of the ring light illuminator is increased.

[026] A beam shaper according to the invention, which may be used in a ring light illuminator according to the invention, but may also be employed for other purposes, is manufactured as one piece, so that the need to properly align plural parts of a beam shaper during assembly of an optical system is obviated. Also, the number of parts that need to be handled is reduced in this way. The beam shaper is made of a material which is transparent for the light wavelengths the beam shaper is to be used for. In embodiments, such a material can for example be a plastic material or glass.

[027] One possibility of the molding material for the beam shaper is acrylic, another one would be polycarbonate. Acrylic has better transmission than polycarbonate but is less capable of withstanding elevated temperatures. Acrylic should be ok for applications where the illumination source does not produce a lot of excess heat. The transmission losses in acrylic are roughly 0.25% per mm which results in a 15% loss in case the beam shaper has an overall length of 67 mm.

[028] The beam shaper according to the invention comprises a light collector, configured to collect light from a light source used with the beam shaper. The beam shaper also comprises a

homogenizing rod, which is directed along an optical axis of the beam shaper. The light collector is arranged to direct the light it collected into the rod through a first end of the rod. The rod effects a homogenization of the light passed through it by reflection, typically multiple reflection, of the light from the sides of the rod. The reflection is total internal reflection. The beam shaper furthermore comprises a lens, which images a second end of the rod opposite the first end into an area to be illuminated.

[029] A cross section of the rod perpendicular to the optical axis of the beam shaper in embodiments may be circular, elliptical, triangular, square, rectangular, hexagonal, octagonal or of any other shape.

[030] The invention can be implemented in a microscope assuring a well-defined illumination, in particular of the dark field type, of an area inspected with the microscope. A microscope comprises at least one ring light illuminator according to the invention as described above. The beam shapers used in the at least one ring light illuminator can be of the one piece type according to the invention described above, but may alternatively comprise a light collector, homogenizing means and imaging means provided as more than one piece.

BRIEF DESCRIPTION OF THE DRAWINGS

[031] The nature and mode of operation of the present invention will now be more fully described in the following detailed description of the invention taken with the accompanying drawing figures, in which

[032] Figure 1a shows a prior art ring light illuminator with annularly arranged ends of optical fibres;

[033] Figure 1b shows a prior art ring light illuminator with annularly arranged light sources;

[034] Figure 2 shows the intensity distribution achievable with a prior art ring light illuminator as shown in figure 1b;

[035] Figure 3 shows a TIR lens and light rays as well as the intensity distribution created by it on a surface;

[036] Figure 4 shows an aspheric condenser lens and light rays as well as the intensity distribution created by it on a surface;

- [037] Figure 5 shows a compound lens and light rays as well as the intensity distribution created by it on a surface;
- [038] Figure 6 shows a beam shaper according to the invention and light rays;
- [039] Figure 7 shows the intensity distribution created on a surface by the beam shaper of figure 6;
- [040] Figure 8 shows the intensity distribution achievable with a ring light illuminator according to the invention;
- [041] Figure 9 is a perspective view of a beam shaper according to the invention;
- [042] Figure 10a is a perspective view of a light collector and a homogenizing rod;
- [043] Figure 10b is another perspective view of the light collector and the homogenizing rod of figure 10a;
- [044] Figure 11 shows a light source introduced into a cavity in a light collector with a homogenizing rod;
- [045] Figure 12 is a top view of the cavity in a light collector; and
- [046] Figure 13 is an embodiment of a possible implementation of a plurality of beam shapers arranged in ring to constitute the ring-illuminator according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

[047] Same reference numerals refer to same elements throughout the various figures. Furthermore, only reference numerals necessary for the description of the respective figure are shown in the figures. The shown embodiments represent only examples of how the invention can be carried out. This should not be regarded as limiting the invention.

[048] **Fig. 1a** shows a setup for a prior art ring light illuminator **10**. An arc lamp **12** is used as a light source; light from the arc lamp **12** is coupled into plural optical fibres **11** by suitable optical elements **13** (only one such element is shown in the drawing). Ends **14** of the optical fibres **11** are arranged annularly in a ring shaped carrier **17** of the ring light illuminator **10**, in such a way that they emit the light from the arc lamp **12** towards a area **15** to be illuminated circumscribed by the carrier **17**. As is indicated by the cones **16**, the light is emitted from the

ends **14** with a considerable divergence, meaning a divergence too large for many precision applications.

[049] **Fig. 1b** shows another setup for a prior art ring illuminator **20**. In an annular carrier **27** plural light sources **22** are arranged in an annular fashion. The light sources **22** emit light towards an area **15** to be illuminated. The light sources are LEDs, which typically are provided with shaping optics (not shown) to concentrate the light emitted from the LEDs around a predefined direction. As indicated by the cone **26**, despite the shaping optics the light from a single light source exhibits a divergence that is too large for many precision applications. A ring light illuminator according to the invention has the same general setup as the prior art ring light illuminator shown; however, the prior art shaping optics are replaced with beam shapers according to the invention, of a configuration described below.

[050] **Fig. 2** shows the intensity distribution **1** achievable with a ring illuminator **20** as described in the context of **Fig. 1b**, comprising eight light sources with TIR lenses (see **Fig. 3**) as shaping optics. The illumination pattern is rather diffuse. The central region of the image shown is only moderately brighter than the regions illuminated by one of the cones **26**, indicating that a considerable amount of intensity is directed towards off-centre regions of the area shown in the image rather than towards the central area **15** to be illuminated. The intensity distribution achievable with a ring illuminator **10** as described in the context of **Fig. 1a** is similar.

[051] **Fig. 3** shows a TIR (total internal reflection) lens **23**. Light, indicated by light rays **100**, from a light source **22**, which here is an LED, is captured by the TIR lens **23** and directed towards a spot **110**. Directing the light is achieved by two principles: A refractive lens portion **24** occupying a central part of the TIR lens **23** directs light rays **100** towards the spot **110** by refraction. Light rays **100** not hitting the refractive lens portion **24**, but captured by the TIR lens **23**, are directed towards the spot **110** by total internal reflection from a side surface **25** of the TIR lens **23**. Also shown in **Fig. 3** is the intensity distribution **2** of the spot **110** on a surface perpendicular to an optical axis **19** of the TIR lens **23**. The intensity distribution **2** created by the TIR lens **23** is roughly Gaussian, so that there is maximum intensity in the centre of the spot **110**, but there are also wide regions around the centre in which the intensity tails off, i.e. there are no clearly defined edges of the spot **110**. A TIR lens **23** as described here can be used as shaping optics for a prior art ring illuminator **20** as described in the context of **Fig. 1b**. The intensity distribution **2** of the spot **110** without clearly defined edges is

the reason why the intensity distribution **1** created by a cooperation of eight such combinations of light source **22** and TIR lens **23** is rather diffuse, as is evident from **Fig. 2**.

[052] **Fig. 4** shows an aspheric condenser lens **33** and light rays **100**. As light source in this figure an emitter **32** of an LED is shown schematically. The aspheric condenser lens **33** captures light from the light source and directs it onto a spot **110**. Also shown in **Fig. 4** is the intensity distribution **3** of the spot **110** on a surface perpendicular to an optical axis **19** of the condenser lens **33**, which is an image of the LED light emitter **32**. Directly imaging the LED emitter **32** as in this case introduces high non-uniformity risks of the illumination of spot **110**. Therefore the homogeneity of the intensity distribution created in an area to be illuminated by a ring light illuminator **20** of the type shown in **Fig. 1b**, with LEDs as light sources and aspheric condenser lenses **33** as shaping optics is not guaranteed to be sufficient for precision applications. Furthermore, typically the light collection efficiency of an aspheric condenser lens **33** as shown in **Fig. 4** is lower than the light collection efficiency of a TIR lens **23** as shown in **Fig. 3**.

[053] **Fig. 5** shows a compound lens **40** comprising a hemisphere lens **41** to collect light, indicated by light rays **100**, from a light source **42**, and a relay lens **43**, which directs the light onto a spot **110**. Also shown in **Fig. 5** is the intensity distribution **4** of the spot **110** on a surface perpendicular to an optical axis **19** of the compound lens **40**, which is an image of the flat back surface of the hemisphere lens **41**, which is facing the light source **42**. Such a setup has a lower light collection efficiency than a TIR lens **23** as described in **Fig. 3**, and is incompatible with encapsulated LEDs, which is a disadvantage in the assembly of an optical system like the ring light illuminator **20** of **Fig. 1b**.

[054] **Fig. 6** shows a beam shaper **50** comprising a light collector **60**, a homogenizing rod **70**, a cone section **52**, and a lens **80**. A light source (not shown) is inserted in the light collector **60** and emits light indicated by the light rays **100**. The light collector **60** collects light from the light source and directs it into the homogenizing rod **70**, through a first end **71** of the homogenizing rod **70**. In the homogenizing rod **70** the light is homogenized by reflection, typically multiple reflection, from the side surfaces **73** of the homogenizing rod. The beam shaper **50** is manufactured as one piece from a material that is transparent for the wavelengths of light the beam shaper is intended to be used with, like for example a plastic material or glass, and the reflection from the side surfaces **73** is total internal reflection. The light exits the homogenizing rod **70** through a second end **72** of the homogenizing rod **70**, and

enters the cone section **52**. From there it reaches the lens **80**, which directs the light onto a spot **110**. The intensity distribution of the spot **110** is an image of the second end **72** of the homogenizing rod **70**. The purpose of the cone section **52** is to establish a fixed distance between the second end **72** of the homogenizing rod **70** and the lens **80**. As the beam shaper **50** is manufactured as one piece, no alignment of individual components, i.e. of light collector **60**, homogenizing rod **70**, and lens **80**, is necessary during assembly of an optical system. This simplifies handling of the beam shaper **50**, and the assembly of optical systems, like for instance a ring light illuminator **20**, of the type shown in **Fig. 1b**; contrary to prior art, however, beam shapers **50** just discussed, rather than TIR lenses, are used as shaping optics in embodiments of ring light illuminators according to the invention. The beam shaper **50** can of course also be used for other illumination tasks and is not limited to ring light illumination.

[055] **Fig. 7** shows the intensity distribution **5** of the spot **110** created by the beam shaper **50** of **Fig. 6** on a surface perpendicular to an optical axis **19** of the beam shaper **50**. The shape of the spot **110** is determined by the cross section of the homogenizing rod **70**, more precisely its cross section at the second end **72**. In the embodiment shown, this cross section has an octagonal shape. As has already been mentioned, different shapes of the cross section are also possible. It should be noted that the spot **110** exhibits clearly defined edges, and, due to the effect of the homogenizing rod **70**, the illumination intensity across the spot **110** is sufficiently homogeneous even for high precision applications.

[056] **Fig. 8** shows the intensity distribution **6** achievable with a ring illuminator according to the invention, which, in the embodiment this figure relates to, comprises eight beam shapers **50** of the type described in the context of **Fig. 6** as shaping optics. This figure should be compared with **Fig. 2**. Due to the clearly defined edges of the light beams created by the beam shapers **50**, which result in the clearly defined edges of the spots **110** shown in **Fig. 7**, in **Fig. 8**, the area **15** to be illuminated is distinctly brighter than its surroundings.

[057] **Fig. 9** shows a perspective view of a beam shaper **50** according to the invention, as has already been shown in **Fig. 6**. Here light rays **100** exiting the lens **80** are shown. The configuration of such a beam shaper **50** has already been discussed in the context of **Fig. 6**. The light collector **60** exhibits a cavity **61** into which a light source (not shown) is to be introduced. The general configuration of the light collector **60** corresponds to that of a TIR lens **23**, as shown in **Fig. 3**. The diameter **82** of lens **80** for imaging regulates the number of beam shapers **50** arranged in the ring-illuminator **20**. The lens **80** has an exit surface **84** that

images the light exiting the homogenizing rod **70** through the second end **72** of the homogenizing rod **70** onto a spot **110**. It is recommended that the exit surface **84** of the lens **80** for imaging is aspheric.

[058] **Figs. 10a** and **10b** are perspective views of a light collector **60** as used for a beam shaper **50** according to the invention, as shown in **Figs. 6** and **9**, as well as in shaping optics for a ring light illuminator according to the invention, which may be composed of several pieces. Only a part of the homogenizing rod **70** attached to the light collector **60** is shown. The rod **70** here has a hexagonal cross section, and the shape of the light collector **60** is adapted to the cross section of the rod **70**, also exhibiting a hexagonal cross section in a section adjacent to the first end **71** of the rod **70**. **Fig. 10b** clearly shows the cavity **61** of the light collector **60**, into which a light source (not shown), typically an LED, is to be inserted.

[059] **Fig. 11** shows a sectional view of a light collector **60** and part of a homogenizing rod **70**. A LED **62** is introduced in the cavity **61** of the light collector **60**. Analogous to the TIR lens **23** of **Fig. 3**, the light collector **60** exhibits a refractive lens portion **64**, which collects light emitted into a central region around an optical axis **66**. The cross section of this region is determined by the shape and size of the refractive lens portion **64**. Light emitted by the LED into a region outside the central region is directed into the homogenizing rod **70** by total internal reflection from a side surface **65** of the light collector **60**.

[060] **Fig. 12** is a top view of the cavity **61** in a light collector **60**, into which a light source like the LED **62** in **Fig. 11** is to be inserted. The cavity **61** and the refractive lens portion **64** have a hexagonal cross section.

[061] **Fig. 13** is an embodiment of a possible implementation of a plurality of beam shapers **50** arranged in ring to form the ring-illuminator **20** according to the invention. The plurality of beam shapers **50** arranged in the ring-illuminator **20** provides a homogeneous illumination for the area **15** to be illuminated. The diameter **82** of lens **80** (see **Fig. 9**) regulates the number of beam shapers **50** arranged in the ring-illuminator **20**. In the embodiment shown here, the diameter **82** of lens **80** is 30 mm, which results in approximately 24 beam shapers **50** arranged in the ring-illuminator **20**.

[062] The invention has been described with reference to specific embodiments. It is obvious to a person skilled in the art, however, that alterations and modifications can be made without leaving the scope of the subsequent claims.

REFERENCE NUMERALS

1, 6	intensity distribution
2, 3, 4, 5	intensity distribution
10, 20	ring light illuminator
11	optical fibre
12	arc lamp
13	optical element
14	end of optical fibre
15	area to be illuminated
16, 26	cone of light
17, 27	carrier
19, 66	optical axis
22, 42	light source
23	TIR lens
24, 64	refractive lens portion
25, 65	side surface
32	LED emitter
33	aspheric condenser lens
40	compound lens
41	hemisphere lens
43	relay lens
50	beam shaper
52	cone section

60	light collector
61	cavity
62	LED
70	homogenizing rod
71	first end of homogenizing rod
72	second end of homogenizing rod
73	side surface of homogenizing rod
80	lens
82	diameter of lens
84	exit surface
100	light ray
110	spot

WHAT IS CLAIMED IS:

1. Ring light illuminator, comprises:
 - a plurality of annularly arranged light sources,
 - a beam shaper is assigned to each light source;
 - a light collector for collecting light from each light source;
 - a homogenizing means following the light collector for light from each light source; and
 - an imaging means for imaging an output of the homogenizing means into an area to be illuminated.
2. Ring light illuminator according to claim 1, wherein the homogenizing means is a rod.
3. Ring light illuminator according to claim 2, wherein the rod and the light collector together form a one-piece unit.
4. Ring light illuminator according to claim 2, wherein the rod, the light collector and the imaging means together form a one-piece unit.
5. Ring light illuminator according to claim 2, wherein the homogenizing function of the rod is based on total internal reflection of light within the rod.
6. Ring light illuminator according to claim 1, wherein the imaging means is an imaging lens.
7. Ring light illuminator according to claim 6, wherein the imaging lens has an aspheric exit surface.
8. Ring light illuminator according to claim 1, wherein the homogenizing means is a texture provided on the light collector.
9. Ring light illuminator of claim 1, wherein each light source comprises at least one light emitting diode (LED).
10. Ring light illuminator of claim 1, wherein the ring light illuminator exhibits plural cooling fins.

11. Beam shaper, comprising:
 - a light collector for collecting light from a light source;
 - a homogenizing rod for homogenizing the light from the light source; and
 - a lens for imaging an end of the homogenizing rod opposite the light collector into an area to be illuminated, wherein the light collector, the homogenizing rod and the lens for imaging are manufactured as one piece
12. Beam shaper of claim 11, wherein the beam shaper is molded from a plastic material.
13. Beam shaper of claim 11, wherein the beam shaper is made of glass.
14. Beam shaper of claim 11, wherein the lens for imaging has an aspheric exit surface for imaging the homogenizing rod onto an area to be illuminated.