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Telecentric Lenses with Collimated Light: Part I, Subtle Defect Detection

For several years, telecentric lenses have been standard products for machine vision. A bit less well used are collimated light sources, although many people are familiar with their advantages. These include sharper imaging, very high efficiency, and greatly reduced sensitivity to low-angle reflections from specular (shiny) surfaces. A telecentric lens and collimated back light are often the perfect combination for critical gauging applications.

In the next three articles we'll explore some practical aspects of using this combination, starting with a type of inspection you might not have considered.

Here we look at detecting subtle refractive defects or inhomogeneities in transparent material such as glass or plastic, or detecting small surface variations in highly specular, otherwise flat material. Such Schlieren-like [http://en.wikipedia.org/wiki/Schlieren] inspection has been known for a long time, but it hasn't been widely applied to machine vision.

Figure 1 shows a portion of a pair of plastic safety glasses that nominally have no optical power. It's imaged with a conventional lens and a diffuse back light. The only significant feature is a human hair deliberately placed in the field of view.

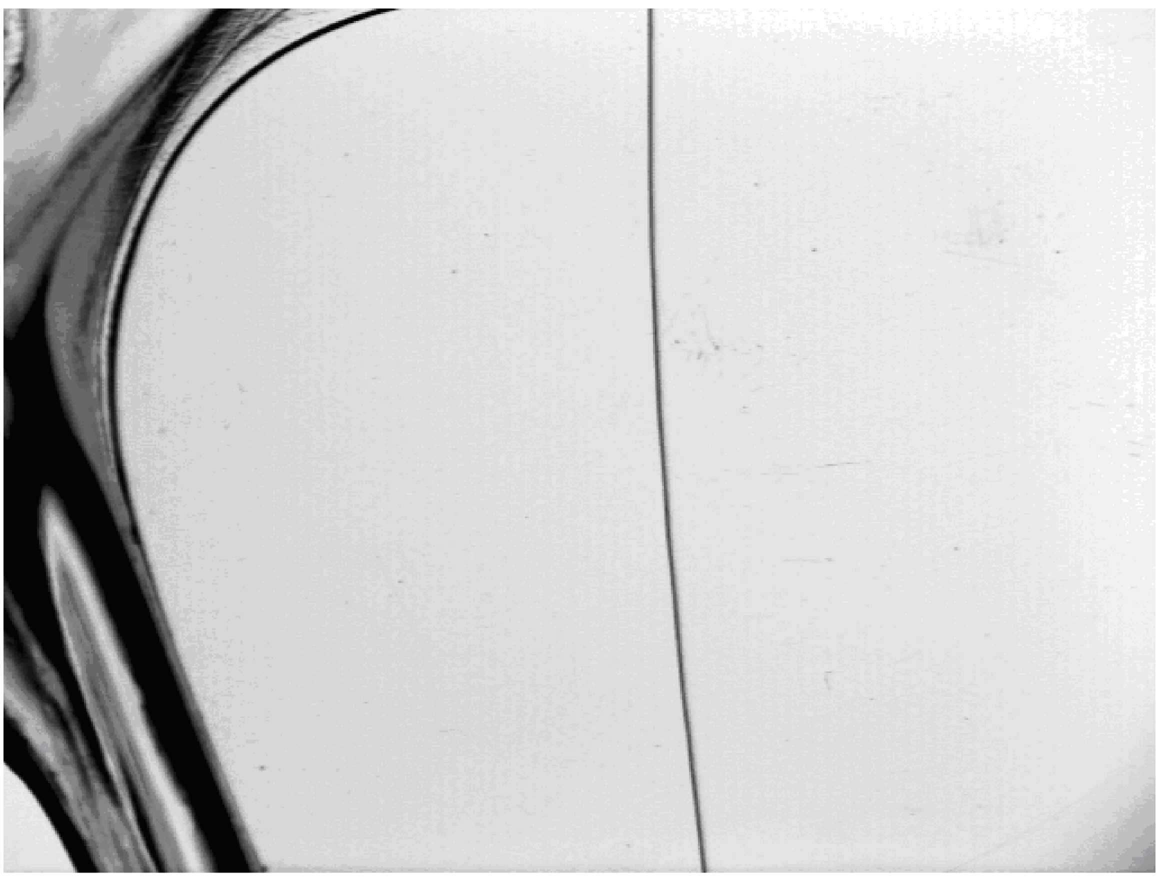

Figure 1: Conventional Lens with Diffuse Backlight

Figure 2 shows the same object, but this time imaged with a telecentric lens. The light source is still a diffuse back light. Notice that now many features appear, including scratches, dirt, and a long, irregularly curved line to the right of the hair. This is a defect called viscous thread. It's a thread of plastic left over from previous molding that didn't quite melt completely. Visually it is extremely faint and in fact this pair of safety glasses is commercially acceptable.

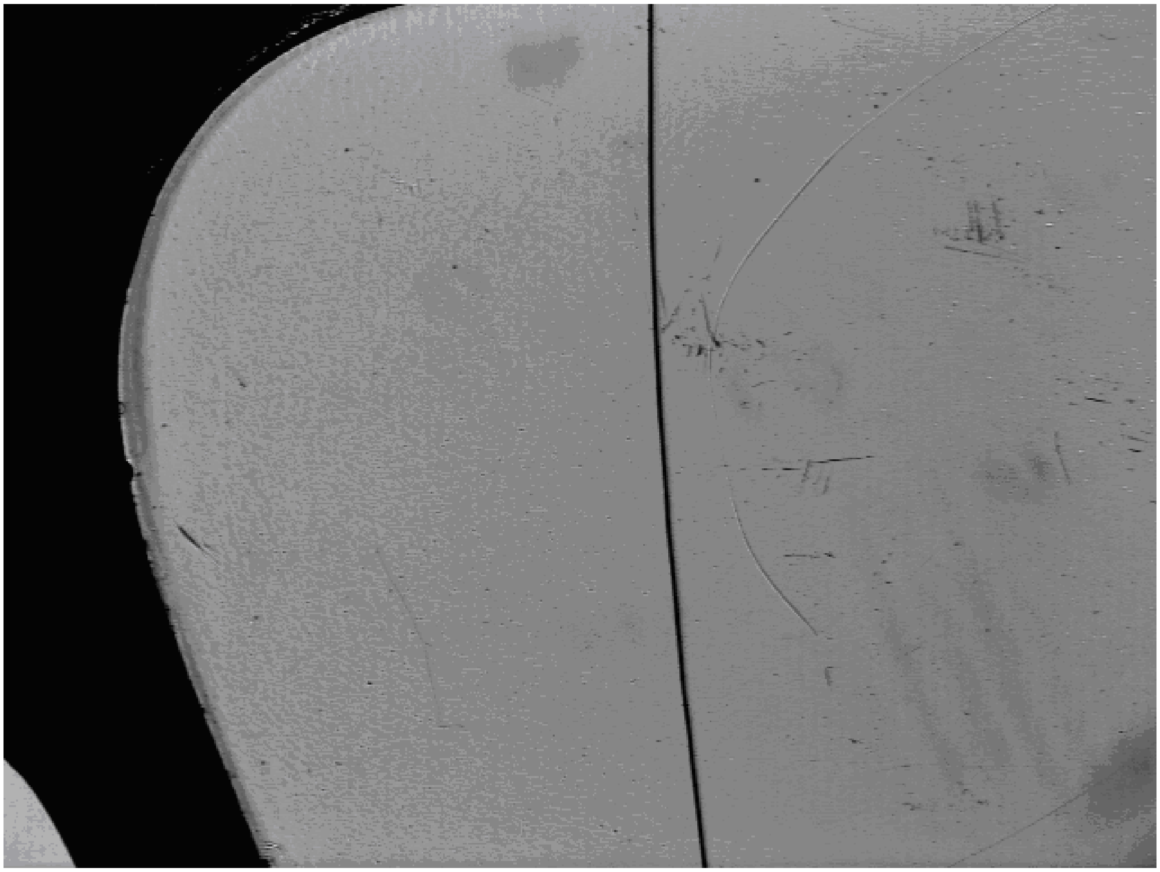

Figure 2: Telecentric Lens with Diffuse Backlight

Finally, Figure 3 shows the same object imaged with the telecentric lens and a collimated back light. The viscous thread is much more prominent. We also see a region at the lower left where one surface of the plastic is mildly deformed or "prismed" over a large area. One can also observe a slight graininess over the whole field, the result of subtle surface texture.

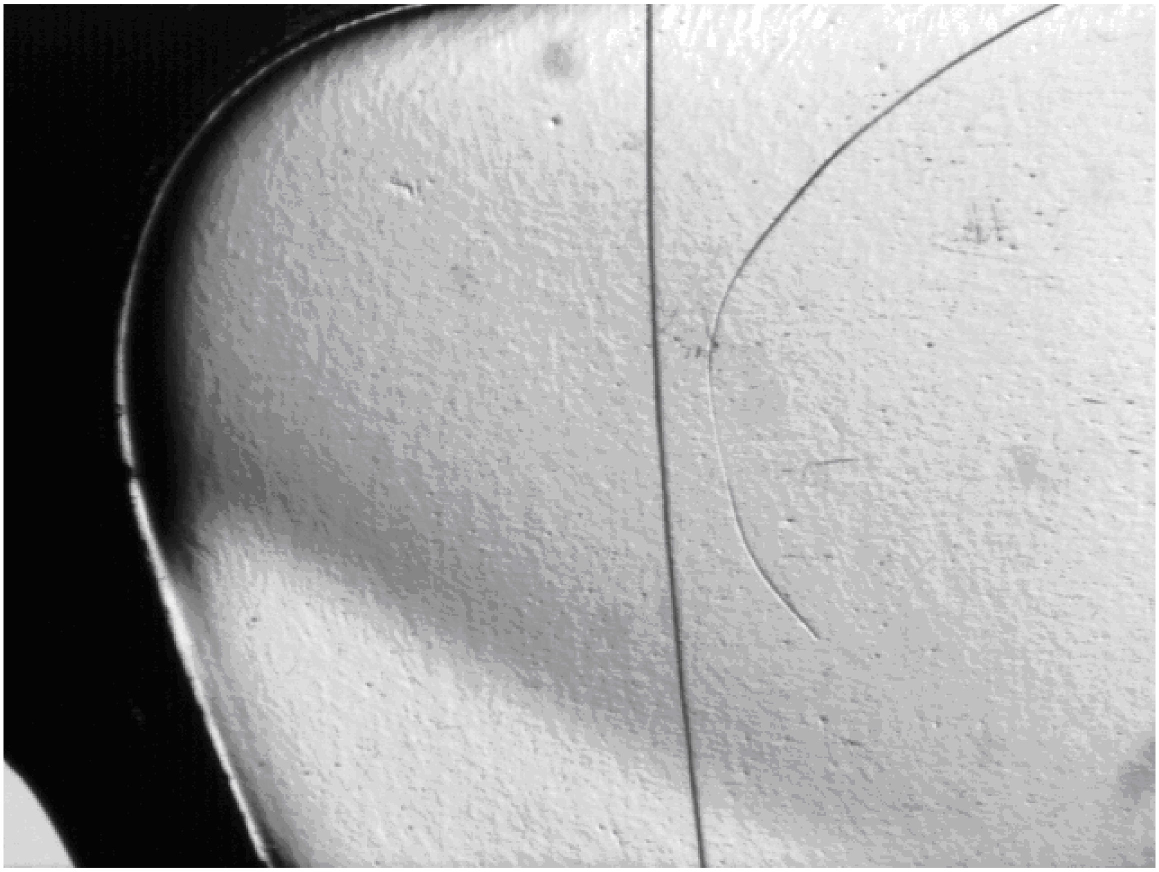

Figure 3: Telecentric Lens with Collimated Backlight

The same results can be found when inspecting many other transparent materials. It's a powerful technique for detecting otherwise "invisible" defects or features.

Next post we'll look into aligning and adjusting collimated lights with telecentric lenses.

Telecentric Lenses with Collimated Light: Part II, Alignment

A practical challenge when using collimated light with telecentric lenses is alignment and adjustment. The collimator is simply a small light source (**S**) at the back focus of a collimating lens (**C**). Rays from the source hit the lens and come out mostly parallel. (How parallel depends on the size of the source, the lens focal length, and other factors not discussed here.)

The parallel light then enters the first receiving element (**R**) of the telecentric lens and converges to form an image (**I**) at the entrance pupil (**E**) of the telecentric lens. (**C** has a focal length **F1** and **R** has focal length **F2**). See Figure 4.

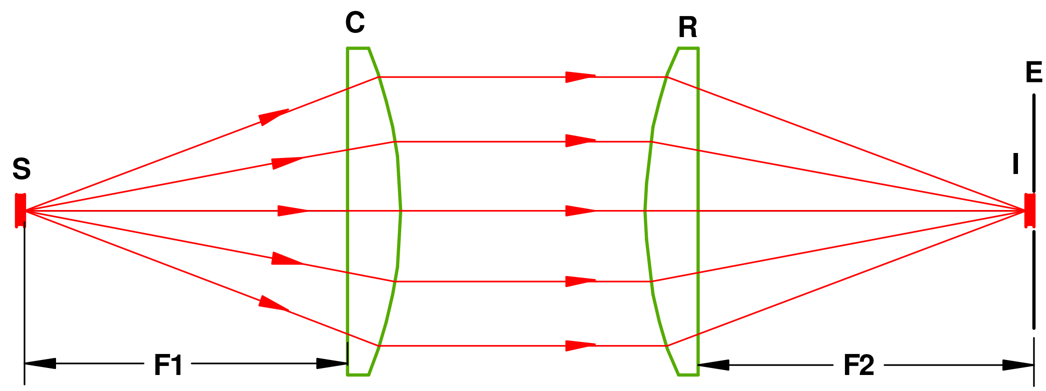

Figure 4

*[NOTE: Ray trace and image formation **not** shown completely accurately]*

If the lenses are properly aligned and the image **I** is smaller than **E**, all the light enters the lens and is useable.

But what if the alignment is off? Figure 5 shows **C** being shifted up, but still with the correct angle relative to **R**.

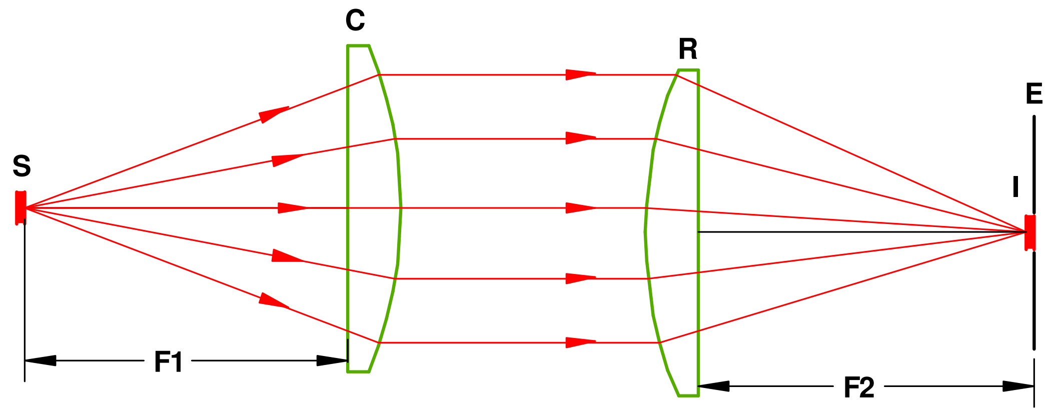

Figure 5

Here we see that the image of the light source still completely "falls into" the entrance pupil, and will be useable, and most of the image will be uniformly bright. The problem is that the lower portion of the field viewed of **R** won't be illuminated at all.

This condition by itself tends to be obvious when viewing a live image on your monitor—uniform illumination except for a fairly sharp-edged dark region. You can also check for it with no monitor. Take plain white paper and hold it at the front of the telecentric lens. You can then see if the disc of collimated light is centered on it.

Unfortunately, the paper trick doesn't help discriminate between light source shift and angular misalignment. The off-angle condition is shown in Figure 6.

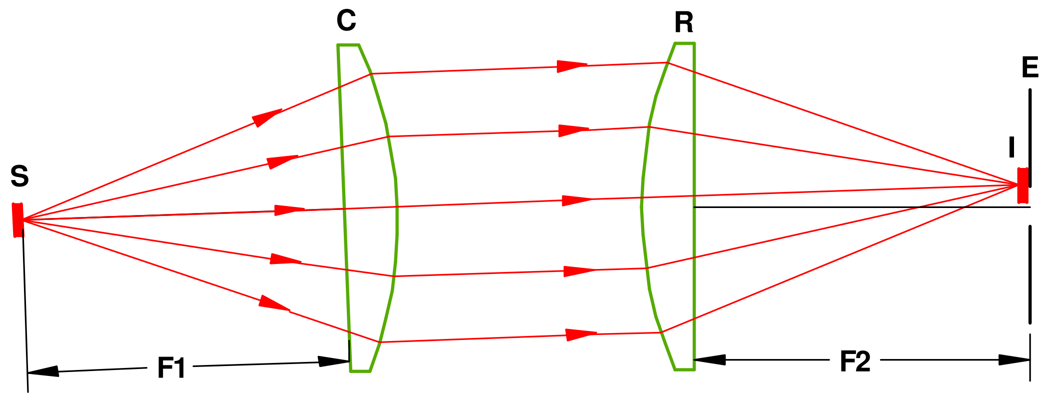

Figure 6

For this case, **I** is not completely contained by **E**. The *overall* light level as seen at the monitor will be reduced. Furthermore, the system will have asymmetric sensitivity. That is, defects that redirect light in one direction won't produce the same signature as otherwise identical defects that redirect light in another direction. This is bad!

The way to check for angular misalignment is to look down the barrel of the telecentric lens and observe **I** on the surface of **E**. (A small dental mirror can be of great use.) It's best to do this with the room lights off. Adjust the collimator angle until **I** is well-centered. If **I** is smaller than **E**, it will be "lost" in the hole. Temporarily increase the telecentric lens f-number to make **E** smaller. You can iterate between checking for shift and checking for angle until everything is perfect.

In part 3, we'll discuss more alignment/adjustment issues.

Telecentric Lenses with Collimated Light: Part III, Spot Size (I)

Last time we looked into shift and angular alignment of collimated light with a telecentric lens. This time we'll consider the size of the image spot (**I**) of the source (**S**) as compared to the size of the telecentric entrance pupil (**E**). [*Please see Part II for earlier details*.]

If (**I**) is the same diameter as (**E**), then the lens and the collimator will be perfectly matched in terms of angular sensitivity. The problem is that there will be no tolerance for misalignment. Any deviation, even due to vibration, will mean that (**I**) shifts position and some light will not enter the lens. This causes an overall signal drop.

There are two solutions: 1) Make (**I**) smaller than (**E**), or 2) Make (**I**) larger than (**E**). For the former case, the small (**I**) is free to "wander" within the boundary of (**E**) with no change to the overall light level. For the latter case, the large (**I**) can likewise "wander" while (**E**) still collects the same amount of light.

Figure 7 shows (**I**) being small because (**S**) starts small.

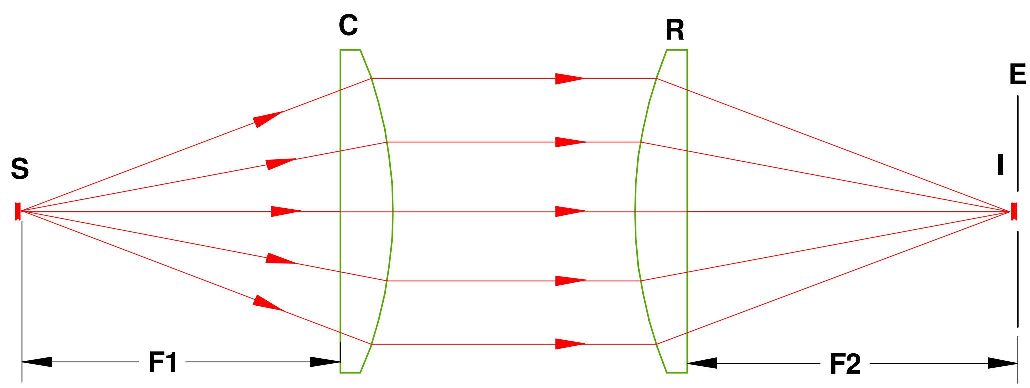

Figure 7

We could make (**I**) larger by starting with a larger (**S**), but another way is to use a shorter focal length (**F1**) collimating lens (**C**). Figure 8 illustrates this.

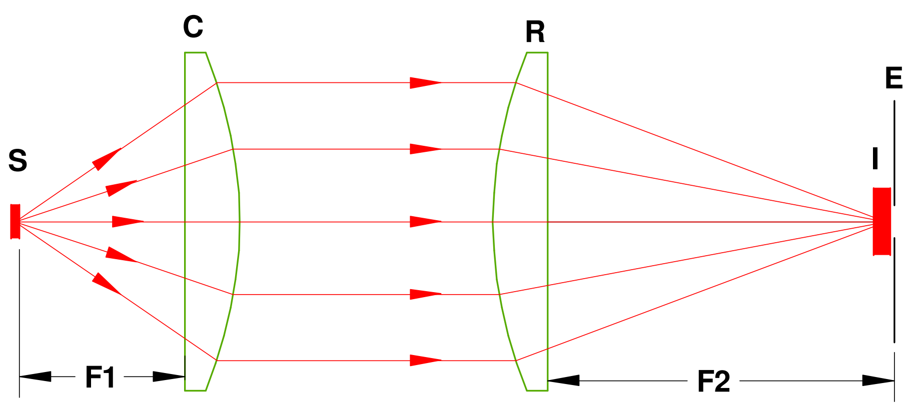

Figure 8

The size of (**I**) is proportional to (**F2**)/(**F1**). Of course you'll almost never know the actual value of (**F2**), but you can control (**F1**) if you're making the collimator.

So, is it better to have (**I**) larger or smaller than (**E**)? Like nearly everything in the universe, it depends. Small (**I**) means greater sensitivity, but it also means less light into the lens. For critical gauging—where low-angle reflection is a serious issue or extreme sensitivity to defects is required—small (**I**) is probably preferred. For less critical applications, or if the system is light starved, the higher collection properties of large (**I**) may be the better choice.

Come back for part IV in which we introduce: **Collimated Dark!** Dun, Dun, DUNNN!

Telecentric Lenses with Collimated Light: Part IV, Collimated Dark.

In Part I we explored using telecentric lenses and collimated lighting for subtle defect detection. We then moved on to alignment and adjustment issues. Now we're ready to take a look at a powerful technique for detecting very subtle defects—Collimated Dark. Figure 9 shows such an arrangement.

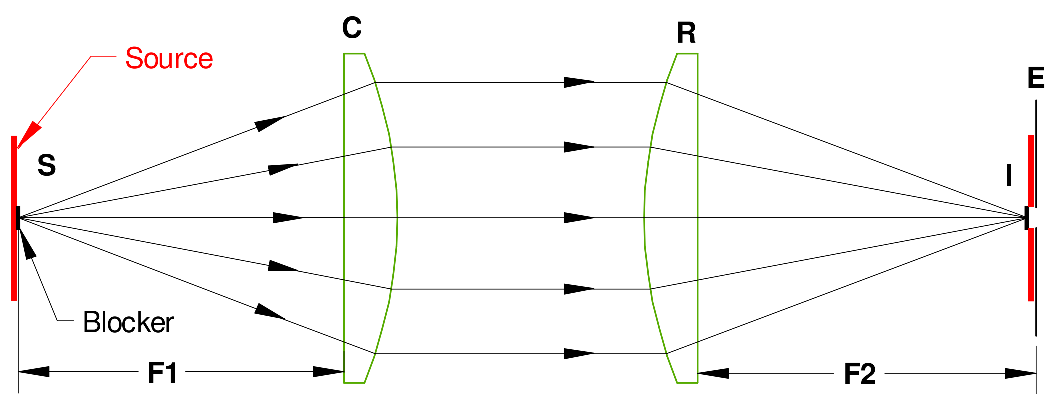

Figure 9

This is the same as for the collimated light set-up, but the source (**S**) is much larger, and a blocker has been added on-axis. The blocker size is chosen so that its image just fills the entrance pupil (**E**) of the telecentric lens. It's as if a "dark source" is emitting "darkons" or "dark rays" toward the telecentric lens. Of course what's really happening is that light from the source is being projected by **C** in many, many directions *except* parallel to the optical axis. Drawing all those light rays, however, would just make a mess, so it's handy to think of dark rays. But remember, *lack* of dark rays equals light.

When no object is between **C** and **R**, or it's just a flat, smooth, transparent object, the dark rays are unchanged and enter the telecentric lens. When a defect deviates a dark ray, however, light enters the lens and a bright signal is produced.

Like most dark field techniques, the otherwise unused source can be made extremely bright and thus produce a highly sensitive system. Why? Suppose a defect in a light field system has a "natural" contrast of 1%. A background of 200 grey levels will only be changed by 2 grey levels for such a defect. Tough to detect. A dark field system, however, could have a source with a theoretical light level of 2,000 grey levels, or 20,000 grey levels. With no defect there is no signal, but if the 1% defect appears, the signal spikes to 20 or 200 grey levels!

Remember the images of the safety glasses from Part I? Let's take a look at exactly the same object, but this time using collimated dark and a very bright source.

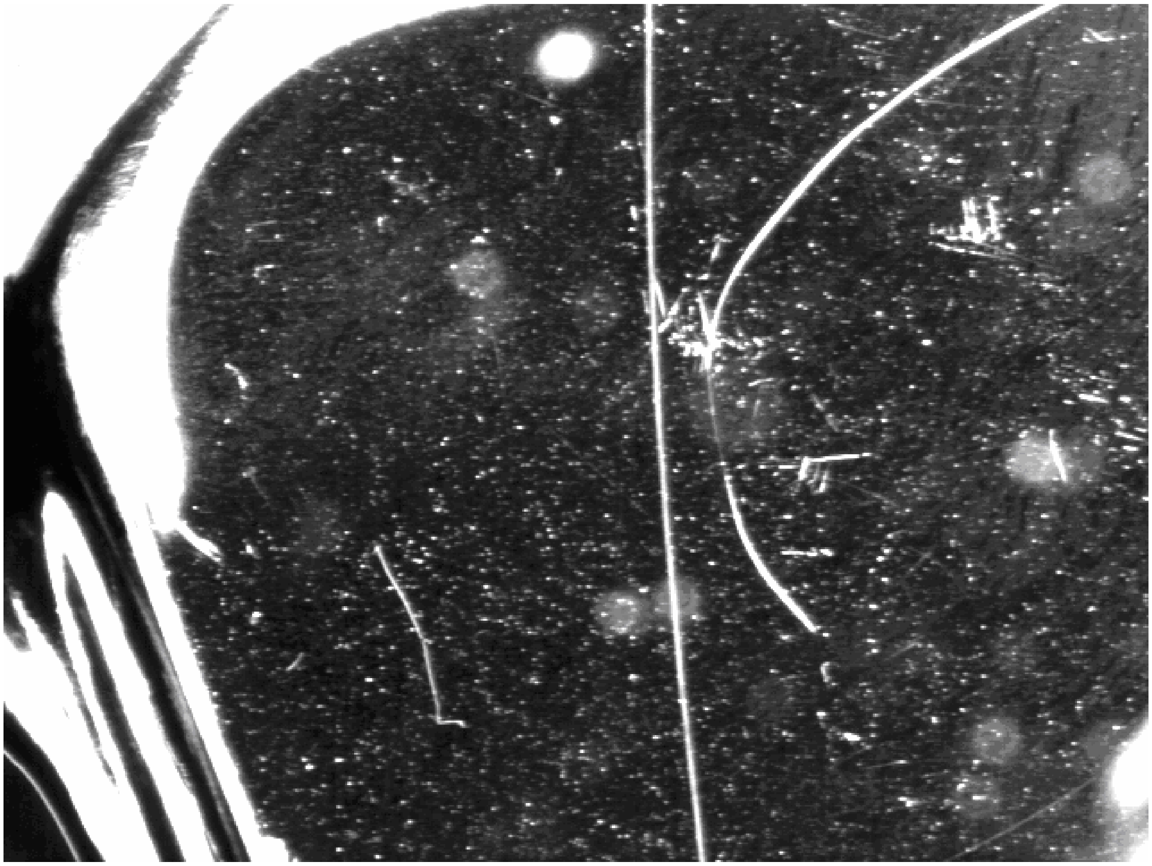

Figure 10: Collimated Dark

Now we see the curved "viscous thread" defect showing up as a bright object because it refracts the dark rays away from the telecentric lens. Furthermore, every little dust speck, and even the long hair that was deliberately placed appears bright with high contrast. Why should such a dark, blocking object show up as bright? The answer is diffraction. We won't go into details here, but the edges of any object deviate rays slightly and produce a weak signal. When the source is very bright, even a weak signal can easily be detected.

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