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Using a LED Flashlight for High Speed Photography in Industrial Settings

Till Haenisch
Professor
Baden Württemberg State University Heidenheim
Germany

Stefanie Haenisch
Voith PaperFabric & Roll Systems GmbH
Germany

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Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
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Using a LED Flashlight for High Speed Photography in Industrial Settings

Till Haenisch

Stefanie Haenisch

Abstract

One challenge in the paper industry is measuring wear of forming fabrics and other materials in different sections of a paper machine. Today these measurements are performed during scheduled shut-downs, typically every two weeks. But since the typical lifespan of these products is in an order of one to six months, a significant safety margin has to be used when measuring only during downtimes. In addition to that, these measurements are costly because they are done by workers of the manufacturing company, who have to travel to the customer's place when the machine is down, and not, when a sales personal is nearby. A simple solution to these challenges would be measuring the wear while the machine is running. This could be done in several ways. One very promising way is by taking photographs at machine speeds between 400 and 2,000 m/minute and yarn diameters between 0.2 and 0.5 mm. Very short exposure times in the level of one microsecond are needed. In this article a low cost LED flashlight is described and evaluated. Possible applications include, but are not limited to, the measuring wear in the paper industry. In all but extreme cases, an air gap flash can be replaced with the described system.

Keywords: Forming fabrics, High speed photography, LED, Quality control

Introduction

Precise measurements of wear of forming fabrics in paper machines are important because of economical reasons: Not using their full lifespan is costly because these fabrics are expensive. But waiting too long can have disastrous consequences. In the worst case, the fabric can be teared in parts, which is no fun at a size of up to 10 meters in width, 50 meters in length and speeds of up to 200 km/h. The economical consequences of such an accident are so serious, that fabrics are changed early. That means, before the end of their full lifespan.

Measuring wear can be done online (while the paper machine is running), by mechanically measuring the thickness of the fabric with a slide gauge. This is not only inexact but also dangerous. Therefore, the preferred method is to measure the fabric while the paper machine is stopped, thing which happens usually every two weeks. When stopped, the fabric can easily be inspected optically with a microscope and by measuring the thickness.

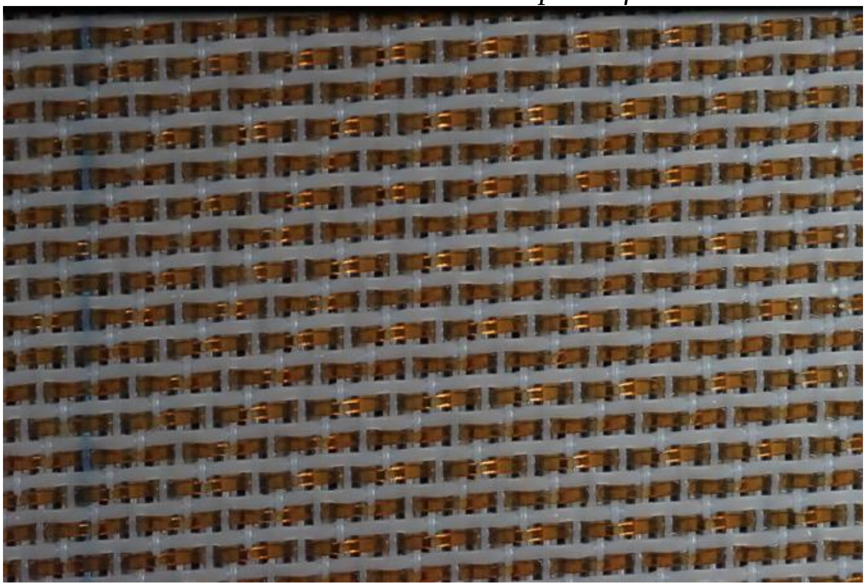
The issue of the first approach is that only the thickness can be measured, thing which does not allow the differentiation between the two sides of the wear, it's low precision and the personal risk induced by manually operating in contact with large, powerful, fast moving parts with sharp edges.

The issue of the second approach is mostly economical: Measurements can be done only, when the machine is stopped. This means, that the service team of the fabric manufacturer has to travel to the site at a specific date. This is expensive very costly procedure. The second, minor, issue is that the remaining runtime has to be extrapolated, which is of limited accuracy, as the wear rate is not a linear function. Because of this, a safety buffer has to be added, that reduces the possible run time and therefore means increased costs.

Because of these reasons, we tested, if it's possible to measure the wear optically, while the machine is running. A second interesting application of measuring online is the possibility to test the hypotheses about the wear dynamics (when and how does wear happen) over a long period of time, in theory even over the complete lifespan of a fabric. This would allow the verification or not of some theories about power consumption during startup, some common hypotheses about this effect assume a difference of wear between different yarns in the fabric.

There are two challengesassociated with this approach. First a very short exposure time is needed to get sharp pictures. With a typical speed of 1,000 m/min the fabric moves some 20 micrometers per microsecond. With a typical yarn diameter of 400 micrometers it is 5% of the diameter. Therefore an exposure time in the range of 1 to 3 microseconds is needed.

Figure 1. *The Thick Yarns Running Horizontally have a Diameter of 0.5 mm, the Thin Yarns 0.26mm. Photo was Taken at a Speed of 420 m/minute*



Commonphotographic flashlights using xenon filled flashtubes have a minimum exposure time of at least 20 microseconds which is too long. In well known examples of high speed photography, like flying bullets, air gap flash lamps are used. They can produce flashes with an exposure time well below a microsecond while achieving a high light intensity by using some 30kV and power levels of some 20kW. While is nice in a lab but difficult to build and handle in an industrial setting with a high humidity and high temperature.

From the manual of a popular DIY air gap flash: "One issue that has happened in the past is humid weather that caused the air gap to either randomly trigger or continuously trigger. Increasing the gap between the electrodes in the flashtube can help reduce this problem, but in very humid environments this issue cannot be solved. You should target humidity levels of 50% or lower for optimal operation." (Ribble, 2013) This is hard to achieve in paper machine former sections, where a lot of water, mist, fibers etc. are all around.

This is the second challenge because a paper machine is a very unfriendly environment for electronics of every kind.

Because of these challenges we used a power LED as a light source. LEDs are fast, cheap and do not have problems with high humidity. There are encouraging use cases of LEDs for high speed photography, esp. microphotography (Willert, 2010). Unfortunately LEDs have a much lower light intensity compared to flash lamps. This is the reason, why it is "common wisdom" that LED flashes do not work (Ribble, 2012). But the efficiency of LEDs increased in the last years so that it's worth investigating if a LED flash can be used for this application.

By using high power LEDs, like the ones used in work spotlights, a sufficient light intensity can be realized over distances of a few centimeters, as some preliminary tests showed. This paper describes a kitchen table effort to develop a LED flashlight fast enough to measure wear of forming fabrics while being bright enough and robust enough to be used in a paper machine.

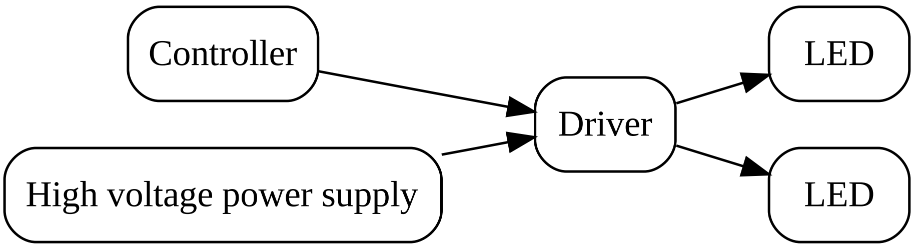
Design

The system consists of a standard high performance camera (Sony alpha 7) with a high quality macro lens (Sony SAL-50M28). High quality optical components are required to get the highest contrast possible, since the details, which are to be inspected, are very small (see Figure 1).

The LED flash consists of a high performance LED. In this case a Cree CXA3590-0000-000R0HCB50F was used (Cree, 2014). With a light intensity of over 12,000 lm, these LEDs were the brightest available to the consumer market at the time of the experiment (Spring 2014). The nominal operating point of these LEDs is 1,200mA at 72 Volts. We used 1,500 mA at 80V. A higher current does not result in a significantly higher light intensity at the speeds required according to our preliminary tests.

The other components of the system (see Figure 2) are the controller which generates the pulses, the LED driver, a capacitor bank for storing energy and a step up converter for creating the required voltage from a 9V battery supply.

Figure 2. *Architecture of the Flashlight*

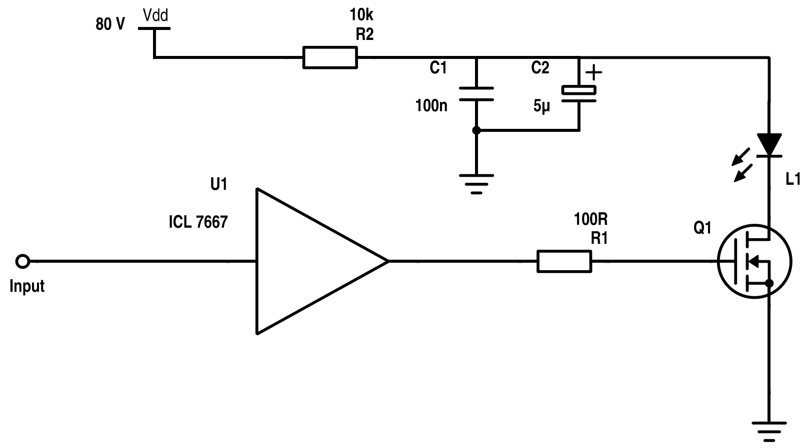


The driver circuit is similar to the one described in (Willert, 2010) and shown in Figure 3.

The capacitors C1 and C2 (actually a bank of 5 low ESR capacitors in parallel) are charged via R2 from the high voltage supply. Their capacity is large enough to allow pulse lengths of a few microseconds but not larger.

The power MOSFET Q1, a IRFR220TR is driven by U1, a ICL 7667 from Intersil which has a TTL compatible input. It provides the current to charge and discharge Q1 with the necessary speed. When U1 is triggered, Q1 connects the cathode of L1 to the ground so the capacitors discharge through this path. R2 limits the current drawn by the capacitor bank. This protects the power supply, the LED and the operator from excess currents in case of accidental connections between the high voltage line and the ground or the cathode of the LED and the ground respectively. It limits the current to a few milliamps which is not dangerous for any of the mentioned parties.

Figure 3. *Simplified Circuit of the LED Driver*



R1 is necessary to prevent Q1 from oscillating because the cable between U1 and Q1 is not short. U1 and R2 are part of the controlling electronics and housed in a separate, isolated case whereas the rest of the driver is in a separate grounded case which acts as a mounting plate for the LED. This has the advantage, that the low impedance connections with high currents are short and shielded in a metal case, while the high voltage part is isolated from the rest of the system. No large currents at high voltages are accessible outside the isolated cases. This is important because of safety considerations and to prevent EMV problems.

Performance Analysis

To investigate the performance of the flashlight system, a fast detector circuit was built. It consisted of a BPW34 photodiode and a fast amplifier. With this circuit the light intensity of the flash light was measured for stimulating pulses with a length between one and two microseconds (the shortest, which showed up useful in practical tests). The pulses were generated by an Arduino microcontroller. This means, that the pulse widths are not very precise, so the measurements presented here have a somewhat qualitative character. But since this (or a comparable) technique will be used in real applications, we saw no necessity in using high precision equipment for these measurements.

Figure 4. *Measured Light Intensity for a 2 Microsecond Pulse*

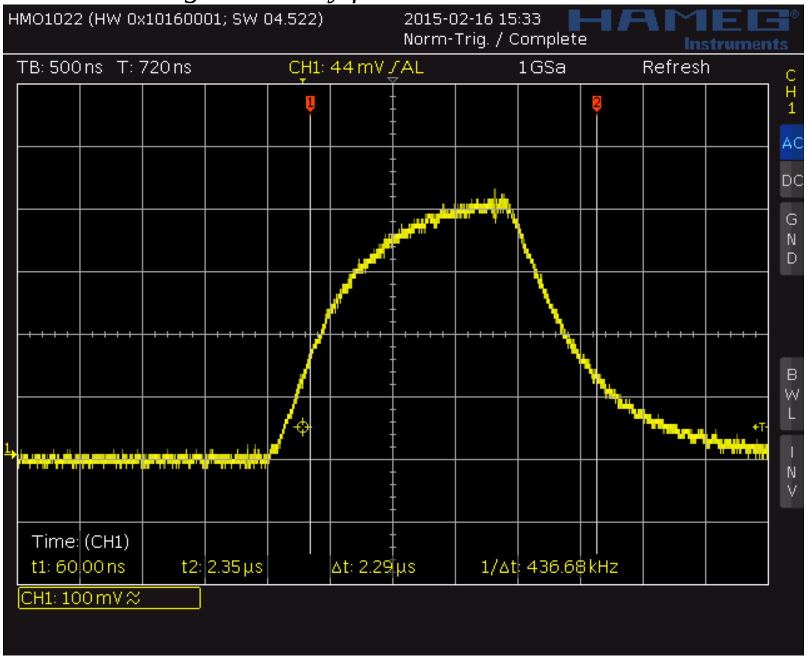
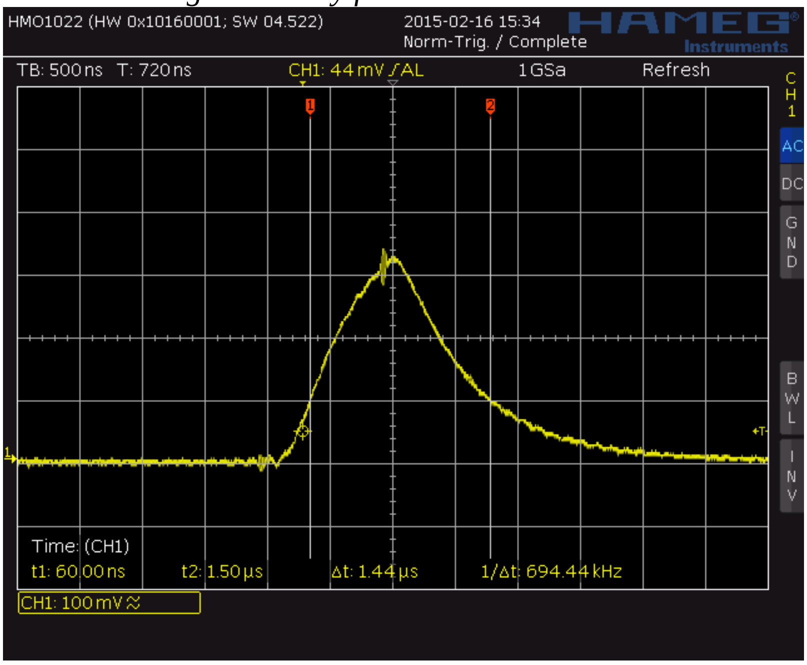


Figure 5. *Measured Light Intensity for a 1 Microsecond Pulse*



The fall time and rise time (0% to 90%) of the intensity is a little more than one microsecond. With a two microsecond pulse shown in Figure 4, the full intensity is reached at the end of the pulse. Longer pulses do not reach a significant higher maximum intensity. With the shorter pulse width of one microsecond, the highest intensity is only 80% of the maximum value of the two microsecond pulse as Figure 5 shows.

If we define the exposure time as the time where the intensity is higher than 30% of the maximum value, the two microsecond pulse results in an exposure time of some 2.5 microseconds, and the one microsecond pulse in an exposure time of 1.5 microseconds. With a different definition, the exposure times may vary a bit, but for practical purposes this makes no difference.

The reason for the rise time of about one microsecond could be the limited slew rate of the power amplifier, the limited output current of the power amplifier, the capacitance of the LED or the limited rise time of the detector.

To exclude the latter, a control measurement with a laser diode (salvaged from a laser pointer) was done. Typically these laser diodes have rise times in the range of some tens to maybe a hundred nanoseconds [Gallant09].

Figure 6. *Measured Pulse Response of a Laser Diode*

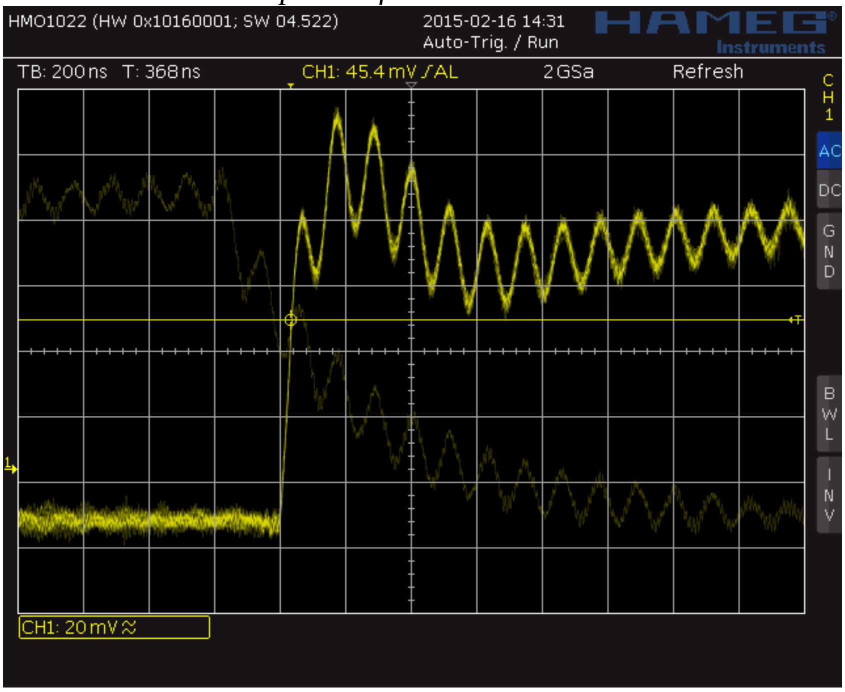
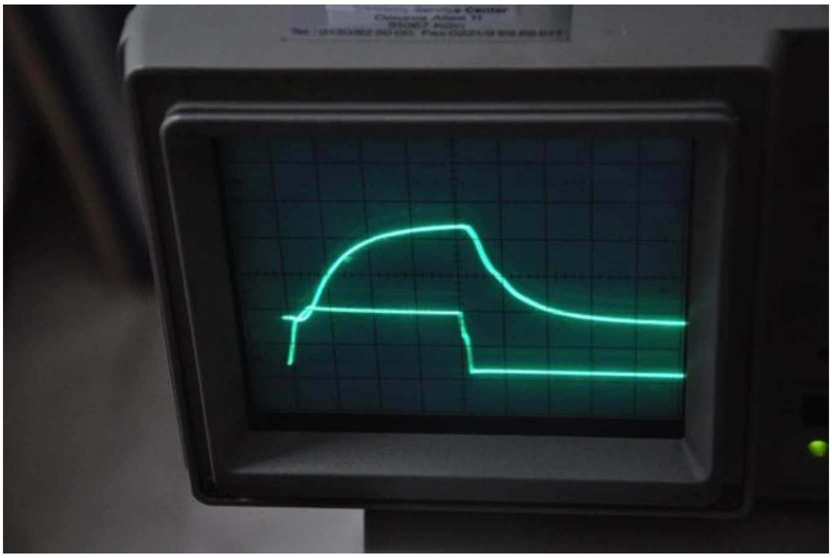


Figure 6 shows that the rise time is on the order of a hundred nanoseconds or faster. It also shows that the detector has some high frequency instability with fast low intensity signals. But they are not relevant at the intensity levels of the main measurements.

This leads to the conclusion that the measured rise time for the power LED is no artifact of the detector but has its reason in the combination of the power amplifier and the LED.

Figure 7. *Driver Current (Lower Curve) vs. Light Intensity (Upper Curve) for a Two Microsecond Pulse. Time Base is 500ns/div*



As figure 7 shows, the rise time of the driver is not the limiting factor. It might be possible to make the rise faster e.g. by peaking, but the amount of light with a one microsecond pulse is barely enough to get useful pictures with a low level ambient light. If the flash is used in darkness, shorter exposure times might make sense. In this case a more detailed analysis (and optimization of the driver circuit) should be performed.

Discussion

In the Internet statements that the light intensity of the LED flashes is too small compared to that of normal flashlights that are available. The flash described in this paper delivers some thousand lumens. This is about a factor of thousand less than a normal flash light. While this is problematic for well known high speed photography like bullets breaking through a window, it is much less severe for macrophotography: In the setting described here, the distance between the camera lens and the object is about 40mm, the distance between the flash lamp and the object is a little bit more (something like 60mm center to center). A normal flashlight produces way too much light at this distance and would have to be dimmed. The LED flash described above can be used at this distance with an exposure time of 1/250 second and a camera sensitivity of ISO 8000 at f 5.6. This is enough for the problem described. In settings with a higher ambient light intensity, that might lead to problems or might require the use of more than one LED. If a larger distance between the flash lamp and the object is necessary, the light of the flash can be collected by a lens. In our experiments, a distance of 50cm is no problem, when a simple Fresnel lens is used.

Conclusions

Wear of forming fabrics can be measured online with a conventional camera and a fast LED flash. The quality of the photos is good enough to assess the remaining runtime of the fabrics. This was demonstrated in real measurements in different paper machines with realistic running speeds. With fast running machines and fine fabrics, it could be validated that an exposure time of one microsecond is necessary to get the required level of quality.

In macro photography LED flashes are an alternative to air gap flash lamps. They provide enough light intensity with a comparable flash time of about a microsecond. They provide a versatile means for low cost optical measurements in industrial settings.

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