Contributed paper

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Three methods for photon migration measurements in pulp

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This paper gives an overview of three promising optical techniques for conducting laser pulses time-of-flight measurements in pulp. The oscilloscope method and time-of-flight lidar method are especially good for fast in-line measurements while a streak camera is superior in the laboratory.

Keywords: time of flight, lidar, streak camera, oscilloscope, pulp measurements.

1. Introduction

The properties of a number of highly scattering materials can be determined by measuring of their optical parameters. These include refractive index, attenuation coefficient, scattering coefficient and anisotropy factor, all of which are wavelength dependent. In anisotropic materials these parameters also depend on the direction of light propagation. Measuring of these parameters is a complicated process which is often impossible to perform in a non-invasive way in real time. Most applications require such measurements to be performed without sample preparation and place a restriction on measurement time. Optical methods of measuring changes in pulp content continue to attract intensive research. One of the most promising techniques, capable of providing invaluable information on pulp, is time-resolved spectroscopy.

A related study performed by Karppinen *et al.* [1] into the properties of pulp used for papermaking employed laser pulses time-of-flight (TOF) measurements. The pulp samples they tested were of low consistency, the maximum value being 0.8%. They concluded that the TOF measurement technique is best suited for measuring fines content. They were the first to use a TOF lidar for pulp measurements [1]. Further studies were performed by Saarela *et al.* who investigated pulps with consistency values as high as 15%. They found that at low consistencies TOF remains unchanged, thus indicating that most of the light pulse remains undeflected. Above a critical value of thermomechanical pulp (TMP) consistency TOF increases, thus indicating that light diffusion is occurring. High consistencies are difficult to measure because the pulp contains air pockets which cause arbitrary variations in the measurements. Saarela and his colleagues were the first to use a streak camera for pulp measurements [2]. The same group also made a case study with a selected filler. The filler was talc and its effect on pulps TOF could easily be distinguished. This experiment was performed with a new-generation lidar [3]. The most recent investigation published is also by Saarela *et al.* This time they used a streak camera. They introduced a theoretical method for determining the long fibre and fines fractions of pulp [4].

1.1. Light and random media

Two things can happen when light encounters the surface between two optically different media. Depending on the angle of incidence and the refractive indexes of the media, the light will either be reflected away from the surface or penetrate the surface and refract. Energy is usually divided between these two phenomena. This law of nature leads to the generalisation that light can travel through an inhomogeneous medium in three different ways. It may propagate along a straight path, in which case we may speak of ballistic light, or along a slightly zigzagging path, referred to as snake light. The third possibility is that light may be multi-scattered, in which case we have diffuse light. In each case light travels at a specific distance through the medium and its time-of-flight depends on the distance travelled and the refractive index of the medium. The three ways are demonstrated in Fig. 1.

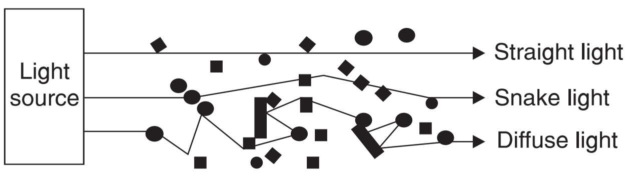

Fig. 1. Light travels through a medium containing arbitrary particles randomly distributed.

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The aim of this paper is to compare three different types of active time-of-flight meters.

2. Measurement settings

Basically, the measurement setting consists of a light source and detection equipment. Pulsed lasers are widely used as light sources. The high peak power they produce enables something measurable to pass through even thick samples. They are wavelength specific which makes it easier to define models. Finally, they are easy to focus. Of course, each particular meter or detector requires a specific kind of laser. The special requirements for each laser are mentioned in the description of the corresponding measurement system.

2.1. Oscilloscope

The measurements are conducted with an oscilloscope equipped with a detecting probe designed by the author. Figure 2 presents a schematic representation of the used probe.

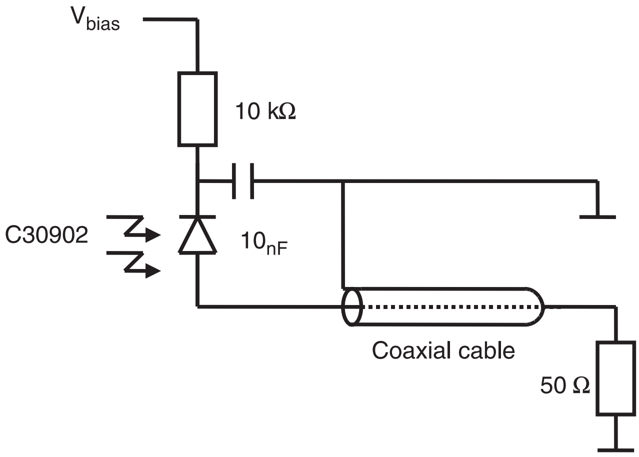

Fig. 2. APD as a sensor for an oscilloscope.

2.2. Time of flight (TOF) lidar

The TOF lidar was originally designed for rapid distance measurements. A laser pulse is aimed at a target and the returning pulse is recorded. Rapid time measurement electronics allow the detection of the laser pulse's echo time. In addition, a discriminator is used to reduce the errors caused by timing jitter, walk, nonlinearity, and drift. Finally, several TOFs are averaged to eliminate statistical errors in calculating the distance to the target. The technique is currently being used in new applications [5].

2.3. Streak camera

A streak camera is a device for measuring of ultra-fast light phenomena. It produces information about intensity versus time versus position. The heart of a streak camera is the streak tube. First, the light being measured passes through a slit and forms an image on the photocathode of the streak tube. Secondly, the light striking the photocathode is converted into electrons, the number of which is proportional to the intensity of the light. This photocathode is the starting point of the streak tube. Thirdly, as the electrons produced by the incident light pass a pair of sweep electrodes, a high voltage is applied to the sweep electrodes at a timing synchronised to the incident light. During the high-speed sweep, the electrons, which arrive at slightly different times, are deflected at slightly different angles in the vertical direction and enter a micro-channel plate (MCP). Fourthly, as the electrons pass the MCP they are multiplied several thousands of times. Finally, the electrons impact against the phosphor screen where they are converted back into light. The phosphor screen is positioned at the end of the streak tube. Figure 3 shows the operating principle of the streak camera. [6].

A streak camera system usually has a triggering section in front of the camera which coordinates incident light pulses and camera operations. After the streak camera, a sensitive camera takes pictures of the phosphor plate. This is in turn followed by image processing tools.

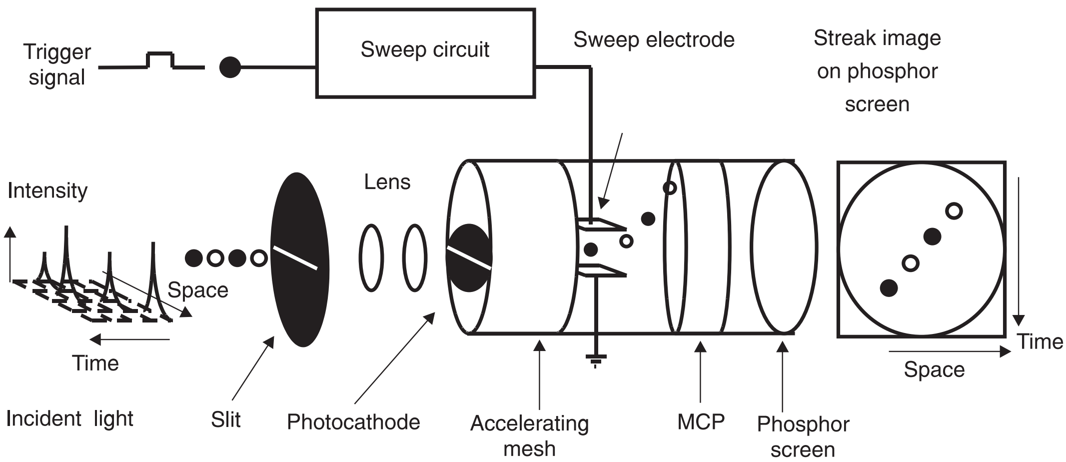

Fig. 3. Principle of streak-camera.

3. Experimental measurements

3.1. Oscilloscope

Our measurement system consisted of two APDs, optical attenuators, a beam splitter, sample, cuvette, and laser-diode. Optical attenuators were necessary for controlling a pulse height. The pulse height was normalized to 30 mV level on the oscilloscope display. The beam splitter divided the light into two beams such that 5% of the original intensity was transferred to the start channel.

The wavelength of the light laser diode emitted was 905 nm. The pulse frequency was 1 kHz. The fall time of the laser pulse was normally 26 ns but when the laser diode module was cooled to –30°C, the pulse broke and the fall time fell to about 1 ns. An avalanche photodiode (C30902) was used as a detector. A signal from the detector was transferred to a 50-Ω load in an oscilloscope. The sampling frequency of the oscilloscope in averaging mode was ten million samples per second. The triggering of the oscilloscope was effected by the falling edge of the pulse.

This measurement technique adapted to TOF applications provides information on the delay of the pulse in the sample. The response time of the detector used was 500 ps. As a consequence, information about changes in the pulse shape is not available in this measuring system. Figure 4 is an example of one particular measurement. The first falling edge represents the start pulse. This is followed by the pulses which have passed through various samples, ranging from water to thick pulp. Accuracy of our measurements was about 20 ps.

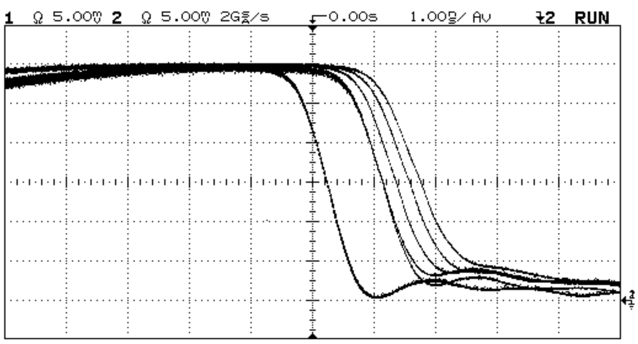

Fig. 4. Typical measurement result with an oscilloscope.

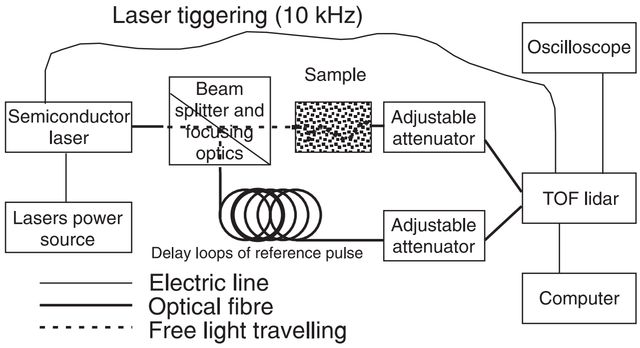

Fig. 5. A measurement setting if using TOF lidar.

3.2. Time of flight (TOF) lidar

For pulp measurements, one possible measurement setting is presented in Fig. 5. A clock in the lidar unit triggers a laser pulse. The pulse length was 8 ns and the pulse power 1 W. The pulse length is lidar specific and cannot be changed significantly because it would make the matching point described later undetectable. The laser pulse is guided using an optical fibre to focusing optics and a beam splitter. The laser pulse is divided by the beam splitter into a start pulse and stop pulse or, in the case of the present study, into a measurement pulse and reference pulse. During measurement, the start pulse is aimed through a target where it scatters. A sample of the laser pulse is taken from the target using a graded index optical fibre. The stop pulse is guided to a delay line consisting of an optical fibre which delays the pulse by about 90 ns. Both samples are attenuated to a constant value. This is necessary in order to perform the lidar timing measurement. Optical fibres guide both pulses into the lidar. With the aid of a photodiode, the light pulses are converted into electrical pulses. Each pulse is then divided into two pulses, one of which is directed through a delay line in order to match the rising and falling edges of the pulse. The two electrical pulses are then guided into a comparator which at the first match starts the time measurement and at the second match stops it. A general description of the signal processing method is presented in Fig. 6.

An earlier version of lidar uses only level triggering, i.e., when the pulse reaches a certain level it is marked as the start or the stop. This method is more sensitive to the changes in laser power, but less sensitive to the changes in a shape of the laser pulse than the double pulse method is.

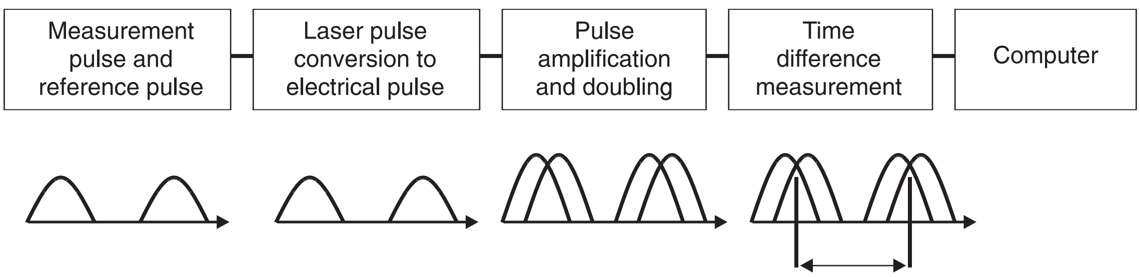

Fig. 6. From light pulses to time difference measurements in TOF lidar.

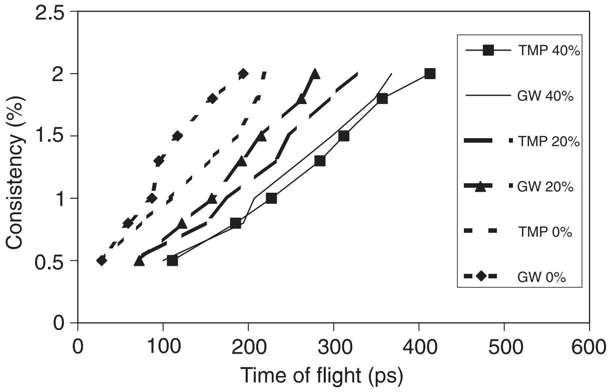

Fig. 7. Time of flight changes as properties of pulp changes.

As an example, six different pulp samples were measured. Ground wood (GW) and thermo-mechanical pulp (TMP) had the fines contents 0%, 20%, and 40%. The results are presented in Fig. 7.

As the pulsation rate of the laser was 10 kHz and 50 000 pulses were measured, it took a total of five seconds to obtain a measurement. This degree of averaging led to a precision of 2 ps.

3.3. Streak camera

For pulp measurements, one possible measurement setting is presented in Fig. 8. The laser should produce a short pulse of high power. The laser in the tested system was a gallium-arsenide laser with a central wavelength of 905 nm at room temperature. It could produce the pulses of 40 ps for full length at half maximum. The nominal pulse power was 100 W. A shorter pulse would be good for modelling. The power of the pulse was too low for measuring of thick samples. More power through can be achieved using 1-cm cuvette than with 2-cm cuvette. At the same time, however, the TOFs decrease as the distance for scattering events decreases.

The laser driver triggers the laser and after a selected period of time gives another triggering pulse to the streak camera sweep circuit. The pulse is aimed using focusing optics at a beam splitter. The beam splitter divides the laser pulse into a reference pulse and a measurement pulse. Since the reference pulse and two measurement pulses ultimately appear on the same streak camera picture, the reference pulse is attenuated to a suitable level. A reference pulse has to be taken because the lasers exhibit drift.

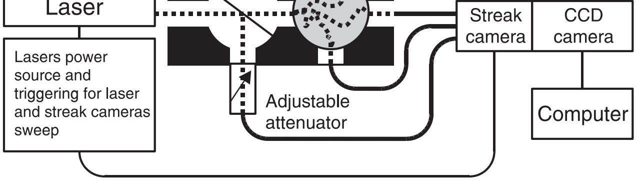

Fig. 8. A measurement setting for using a streak camera.

The measurement pulse enters the sample. As with the reference pulse, a measurement pulse, or as in the presented case, two detected measurement pulses are directed using graded index optical fibres into the input of the streak camera. The optical fibres are placed side by side in a row.

For most samples, the streak camera could be operated at full gain, i.e., 63 MCP but for a few low consistency samples a gain of 30 was used. Two hundred measurements were taken, one on the top of another in order to improve resolution. This took 44 seconds. Over longer measurement times, the sedimentation of low consistency samples would have become a factor affecting the results. Precision of meter is at its best 500 fs, but our laser pulse was so long that a larger timeframe had to be used resulting in a 1-ps precision.

Figure 9 shows a typical intermediate result. The signal has been cut from the original CCD picture, background has been subtracted and some smoothening has been done. Now, it is time to find the attributes that best indicate the pulps changing property. All samples are from thermo-mechanical pulp and have 40% of fines. The thick line represents consistency of 0.1%, next has consistency of 0.5%, and the thinnest one has consistency of 1.5%.

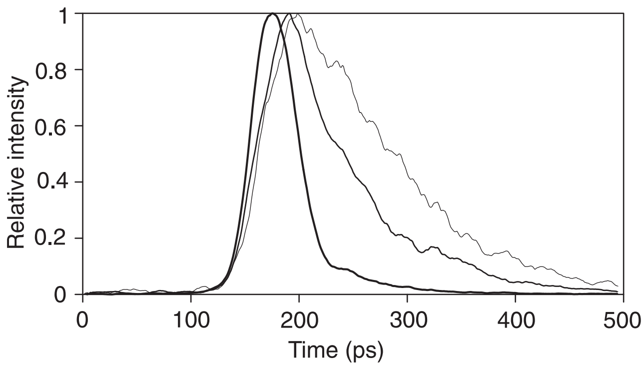

Fig. 9. Shape changes in laser pulse indicate changes in pulp.

4. Conclusions

Five interesting features are collected for comparison in Table 1. The precisions of the meters are in the picosecond range. Accuracy on the other hand depends so much on the system that it could not be determined. The meters are rated in order in terms of sensitivity, i.e., how little light is required to produce a measurable signal. Then, the most important sources of errors are given. After these technical considerations, a price and our view on the most suitable field of application are listed.

The application naturally determines the best system of measurement. A streak camera is the best choice for scientific purpose because of its wider scope. TOF-lidar and oscilloscope are good for industrial applications as they are cheaper and less likely to be disturbed than a streak camera.

Each meter allows the performance of a single measurement which gives a value of time of flight. In applications, however, the interesting feature is usually to what extent

Table 1. Comparsion between different TOF meters.

Meter system	Precision	Sensitivity	Error source	Price ( )	Application
Oscilloscope	~20 ps	Second	Electrical noise	10 000	Industry
Lidar	2 ps	Best	Temperature changes	1 000	Industry
Streak camera	1 ps	Third	Vibration	100 000	Research

the time of flight has changed. Therefore a second measurement to a reference material, such as air or water, is common practice. Each method is also affected by laser pulse changes. Therefore recording a reference laser pulse serves to improve the level of precision.

With all the presented meters, clear changes in photon migration could be seen when pulps consistency, content of fines or content of fillers changes. Meters have to be fast for pulp sediments, especially if consistency is low.

Acknowledgements

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References

1. A. Karppinen, A. Kilpelä, M. Karras, J. Tornberg, and R. Myllylä, *J. Pulp Paper Sci.* **21**, 151–154 (1995).
2. J. Saarela, M. Törmänen, and R. Myllylä, *Proc. SPIE* **4242**, 156–63 (2001).
3. J. Saarela, M. Törmänen, and R. Myllylä, *Proc. SPIE* **5059**, 58–65 (2003).
4. J. Saarela, M. Törmänen, and R. Myllylä, *Meas. Sci. Tech.* **14**, 1801–1806 (2003).
5. M.C. Amann, T. Bosch, M. Lescure, R. Myllylä, and M. Rioux, *Opt. Eng.* **40**, 10–19 (2001).
6. Hamamatsu, *Guide to Streak Cameras*, Cat. No. SSCS1035E02, Japan, 4–5 (1996).

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