Final Report of the Minor Research Project

Design and development of a low cost photothermal beam deflection method and its application for the characterization of optically opaque and highly scattering liquids

Grant Number: **MRP(S)-0326/12-13/KLMG031/UGC-SWRO**

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by

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Annexure - VI

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
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Final Report of the work done on the Minor Research Project

1. Project report no. 1st/Final : Final
2. UGC Reference No. F. : MRP(S)-0326/12-13/KLMG031/UGC-SWRO
3. Period of report : From September 2013 to March 2015
4. Title of the Research Project : Design and development of a low cost photothermal beam deflection method and its application for the characterization of optically opaque and highly scattering liquids
5. Name of Principal Investigator : Dr. Nibu A George
   Department of PI : Physics
   Name of College : Baselius College, Kottayam
6. Effective date of starting of the Project : 23 September 2013
7. Grant approved and expenditure incurred during the period of the report:
   a. Total amount approved Rs. : 1,45,000
   b. Total expenditure : 1,41,719
   c. Report of the work done:
      i. Brief objective of the project:

         Primary objective of this project was development of a cheaper but better alternative to the expensive conventional photothermal setup. Secondary objective was the thermal characterization of liquids having public interest and impact using this setup.

      ii. Work done so far and results achieved and publications, if any, resulting from the work .

         The project is successfully completed with two international journal publications (one accepted and one under review). Four M.Sc Physics students are also used the facilities available in this project for their final projects and they are also the co-authors of the journal publications.

1. Single-beam thermal lens measurement of thermal diffusivity of engine coolants
   Nibu A George, Nibu B Thomas, Kavya Chacko, Neethu V T, Haroon Hussain Moidu, Piyush K and Nitheesh M David
   Journal of Nondestructive Testing and Evaluation (**Accepted for Publication**)
2. Optimization of an optical chopper-laser beam arrangement in low-frequency applications
   Nibu A George, Nibu B Thomas, Haroon Hussain Moidu, and Piyush K
   Optik- International Journal for Light and Electron Optics (Submitted on 16 september 2014)

iii. Has the progress been according to the original plan of work and towards achieving the objective, if not, state reasons : YES

iv. Please enclose a summary of the findings of the study. One bound copy of the final report of work done may also be sent to the concerned Regional Office of the UGC.

v. Any other information : Nil

Signature of the Principal Investigator	PRINCIPAL (Seal)

Detailed report of the project

Single-beam thermal lens measurement of thermal diffusivity of engine coolants

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Abstract

Automobile engine coolant liquids are commonly used for efficient heat transfer from the engine to the surroundings. In this work we have investigated the thermal diffusivity of various commonly available engine coolants in Indian automobile market. We have used single beam laser induced thermal lens technique for the measurements. Engine coolants are generally available in concentrated solution form and are recommended to use at specified dilution. We have investigated the samples in the entire recommended concentration range for the use in radiators. While some of the brands show an enhanced thermal diffusivity compared to pure water, others show slight decrease in thermal diffusivity.

***Keywords*:** Thermal Properties, Engine coolants, Thermal Diffusivity, Thermal Lens

1. Introduction

An engine coolant is a generic term used to describe heat transfer fluids designed to remove excess heat from an internal combustion engine. Proper removal of excess heat in the engine block by the coolant fluid, transport it to the radiator and dissipate it into the environment, is necessary for the engine to operate in an efficient manner. An efficient heat transfer fluid for use in combustion engines will have a low freezing point and an elevated boiling point, ensuring its capacity to perform in all situations encountered in the environment. Water, being readily available and cheap, is one of the most effective cooling substances. But its operating temperature range is limited between 0^0C and 100^0C. Addition of other base fluids such as monoethylene glycol or propylene glycol to water can significantly alter its boiling and freezing temperatures [1]. Another significant problem with the use of water cooling system is that it is corrosive by nature. In order to avoid this, a small percentage of corrosion inhibitor is also added to the coolant fluids. Other minor ingredients of the coolant fluid are scale inhibitors to prevent and remove the formation of scale, antifoam ingredients to prevent the formation of bubbles and aeration, Dyes to differentiate coolant types, bitterant (denaturing fluids) to limit the accidental ingestion of the coolant fluid. In recent years, researchers have proved that adding different types of nanoparticles enhances the thermophysical properties of coolant fluids [2, 3].

In this work we report a laser induced thermal lens technique to measure one of the significant thermophysical properties, namely the thermal diffusivity, of an engine coolant. Commonly double beam thermal lens (TL) technique is used for the thermal diffusivity measurements, in which the pump beam is used to excite the sample and the probe beam at a completely different wavelength to detect the TL effect [4]. However, if the sample is not heavily absorbing at the pump wavelength, then a second probe beam is not necessary, instead the pump beam itself can serve as the probe beam. We have used a single beam transient thermal lens (TTL) technique, in which the sample is locally heated with a Gaussian laser beam and the local rise in temperature and the subsequent change in refractive index is monitored using the same laser beam [5-7]. All the samples investigated in this study were weakly absorbing at the pump wavelength and hence we were able to use the same laser for probing the TL effect. Being an all optical measurement method, TTL requires only a very small quantity of the sample and the measurement and data processing is very fast. Seven different commonly available engine coolants in Indian market are used for the investigations. Commercial engine coolant manufacturers generally do not disclose the exact composition of their cooling fluid or its concentrations. Hence a direct side by side comparison of the different coolants is not ideal. But the manufacturers generally specify the dilution (with water) at which their product is recommended to use. We have measured the thermal diffusivity of each product in the entire recommended concentration range.

2. Theory

The experimental observation and theoretical foundations of thermal lens (TL) effect was first reported by Gordon et al in 1965 [8]. Generally liquids expand on heating, resulting in a concave lens within the heated region and consequently a diverging beam after the sample. Absorption of a TEM_{00} laser beam having Gaussian profile by a thin sample produces a thermal lens whose focal length has a step response, *f(t)*, in the absence of convection, is given by [9,10]

$$f(t) = f(\infty)(1 + \frac{t_c}{2t}) \quad (1)$$

Where t_c is the characteristic time constant, given by

$$t_c = \omega^2/4\alpha, \quad (2)$$

in which ω is the laser beam radius at the sample position and α is the thermal diffusivity in m^2/s and is defined as $\alpha = k/\rho C$. Here *k* is the thermal conductivity, *ρ* is the density and *C* is the specific heat capacity. The effect of the thermal lens on the far-field spot size depends on the position of the sample with respect to the beam waist. The effect is observed to be maximum when the sample is placed one confocal length beyond the waist, where the corresponding far-field transient beam center intensity is given by [9,10]

$$I(t) = I_0\left[1 - \frac{2.303EA}{1+t_c/2t} + \frac{1}{2}\left(\frac{2.303EA}{1+t_c/2t}\right)^2\right]^{-1} \quad (3)$$

Where *A* is the sample absorbance and *E* is the enhancement of the linear portion of the response compared to Beer's law, $E = \frac{P}{\lambda k}(-\frac{dn}{dT})$, where *P* and *λ* and $\frac{dn}{dT}$ are the laser power, wavelength and rate of change of refractive index with temperature. Note the negative sign in $\frac{dn}{dT}$ is due to the fact most liquids on heating expands and hence a decrease in refractive index. In the development of the above discussed derivations, simple parabolic approximation is used, where the thermal lens generated by a continuous wave laser is treated as an ideal thin lens. We have used a least square method to fit the experimentally measured data to equation 3, from which t_c is calculated.

3. Experimental arrangement

In the single beam transient thermal lens configuration, shown in figure 1, we have used a 50mW, 532nm, DPSS laser as the pump as well as the probe laser. In cw TL configuration mechanical chopper operating at very low frequencies are generally used for modulating the cw laser [11, 12]. However, we have estimated that the time taken for the chopper slot edge to cross a reasonable sized laser beam is of the order of few milliseconds, which is not negligible compared to the $\boldsymbol{t_c}$ value. This effect becomes adverse if the number of slots in the chopper blade is larger and or the laser beam is aligned closer to the chopper wheel center. Hence we have designed an electromechanical long-arm type shutter, the response time of which is measured to be around 200 micro seconds. An intensity attenuator is used in the beam path to control the intensity at desired level to avoid the eclipsing effect in the laser beam profile.

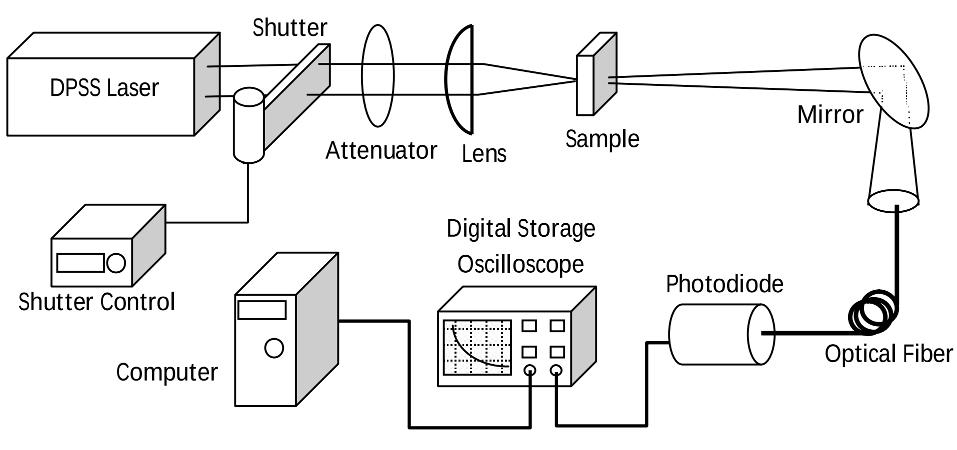

Figure 1. Single beam transient thermal lens setup

Measured diameter of the laser beam is 0.713mm (±0.04mm) and the focal length of the lens used to focus the laser beam is 100 mm. Sample thickness is kept as low as 1.2mm, ensuring the sample thickness is much less than the confocal length. A glass cuvette with an optical path length of 1.2mm is used as the sample container and the liquid sample is carefully injected into the cuvette and removed from it using a syringe, without disturbing the set up. The lens effect is maximized by keeping the photodetector far from the sample. Instead of an aperture in front of the detector, we have used an optical fiber to probe the change in divergence of the laser beam due to TL effect. The optical fiber coupling method increases the flexibility in positioning the detector as well as for adjusting the light level on the detector. We have used a custom made reverse biased photodiode (Vishay Semiconductor GmbH BPW20R) in combination with a low noise opamp (LF356) with adjustable gain and adjustable reverse biasing as the photodetector. The detector output is fed to a 100MHz digital storage oscilloscope (Rigol DS1102E). The data acquisition procedure is fully automated such that when the shutter is opened, the photodiode output triggers the DSO and the TTL signal is automatically saved in the DSO. The saved TTL data is then transferred to a PC and curvefitting is carried out using least square method in Microsoft excel solver.

4. Results and Discussion

We have used seven different engine coolants from six different manufacturers. Two of the coolants were from the same manufacturer, but of different type, distinguished by different colours. All the samples used here are of concentrated type, which has to be diluted in specific ratio with water for using them in radiators. It is very important to note that different manufacturers recommend different dilutions and hence it can be assumed that the original products are of different concentrations. In order for a fare comparison between the samples, we have diluted the samples in the recommended concentration(s) as given in the table below and the thermal diffusivity of each sample at all these concentrations are compared with that of deionized water. In order to estimate the thermal diffusivity value, we must know the precise value of the beam spot size at the sample position and a theoretical estimation of the spot size may significantly differ from the actual value, which in turn can lead to an erroneous thermal diffusivity calculation. Hence we have initially calibrated the experimental setup using deionized water, whose t_c value is calculated using a theoretical fit of equation 3 to the experimental data. Using the measured characteristic time ($T_{c(ref)}$) of water and its known thermal diffusivity (α_{ref}), the thermal diffusivity of coolants were calculated using equ (2). Here the beam waist ω is cancelled on taking the ratio of equ (2) for water reference and the unknown sample (coolant). Figure 2 shows typical transient thermal lens signal from a coolant sample and the theoretical fit of equation 3 to the data.

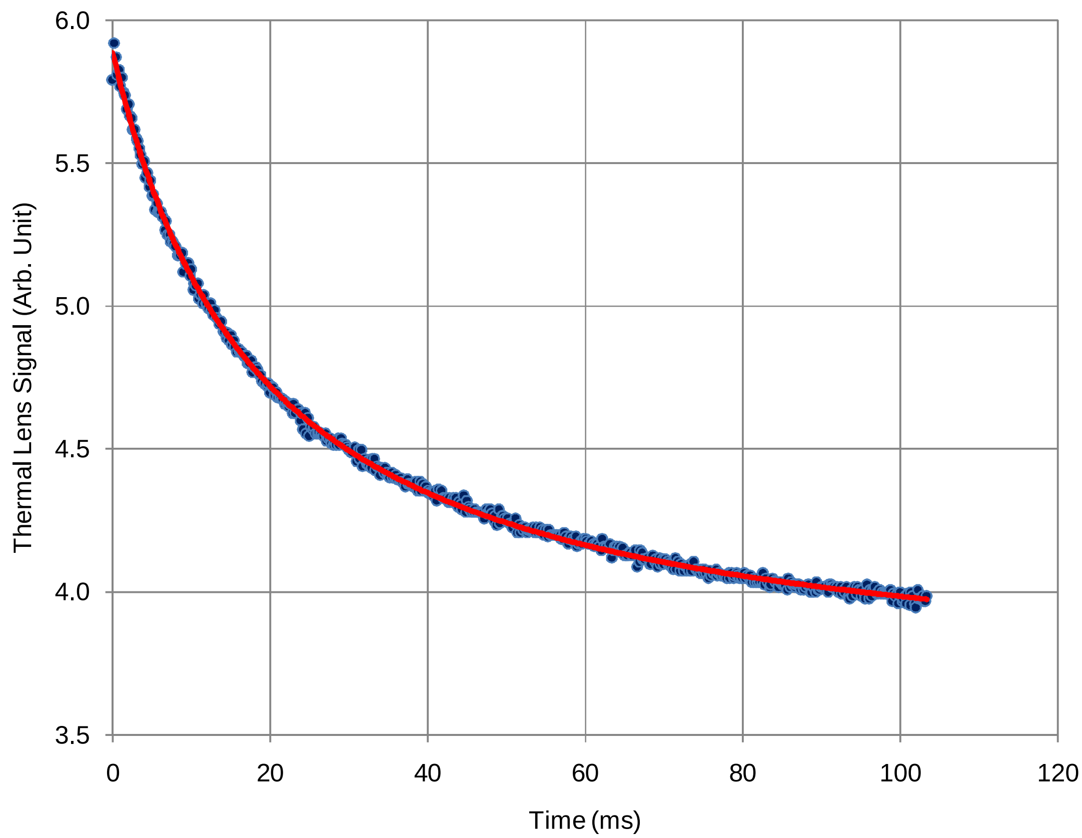

Figure 2. Typical transient thermal lens signal from Valvoline Super Kool (1:6 dilution) sample and theoretical fit to the data. Laser power is 50mW. Fit parameters are, I_0=5.89, t_c=49.08ms, and constant= -0.4958.

Table 1: Thermal diffusivity of various engine coolants measured using transient TL method.

Sample code	Recommended coolant concentration in water (in %)	Tc (ms) (±0.5%)	Thermal diffusivity $\times10^{-7}$ m^2/s (±0.5%)	Change in thermal diffusivity wrt water (in %) (±0.5%)
Pure Water	0.00	62.15	1.430	0.00
Valvoline super kool	12.50	47.93	1.702	19.01
	14.29	49.08	1.662	16.22
	16.67	53.71	1.519	6.20
	20.00	62.74	1.300	-9.09
Gulf e-cool	12.50	47.24	1.727	20.75
	14.29	48.11	1.695	18.56
	16.67	55.58	1.468	2.63
	20.00	53.73	1.518	6.16
Veedol Rapid Kool	12.50	55.95	1.458	1.95
	14.29	58.28	1.400	-2.13
	16.67	58.51	1.394	-2.51
	20.00	59.59	1.369	-4.28
Mahle Red	25.00	55.44	1.471	2.89
	33.33	55.06	1.481	3.60
	50.00	65.79	1.240	-13.30
Mahle Blue	25.00	51.09	1.597	11.65
	33.33	68.21	1.196	-16.38
	50.00	81.22	1.004	-29.77
Maxicool*	25.00	61.21	1.333	-6.81
	33.33	66.56	1.225	-14.30
	50.00	82.99	0.983	-31.27
TVS Girling EzCool	20.00	79.92	1.021	-28.63
	25.00	109.20	0.747	-47.77
	33.33	206.44	0.395	-72.37

Maxicool is a local brand made in Kerala, India.*

Measured thermal diffusivity values, together with that of water, which is used for diluting the original coolant solutions are given in table 1. One can see a clear difference in the performance of the coolants in terms of the thermal diffusivity. Thermal diffusivity is the measure of thermal inertia of a material. It is essential for the transient process of heat flow and gives an insight into the rate of change in temperature as given by $\alpha \frac{\partial^2 T}{\partial r^2} + \frac{q_g}{\rho C} = \frac{\partial T}{\partial t}$, where q_g is the internal energy generated per unit time and per unit volume [13]. The physical significance of thermal diffusivity is associated with the transmission of heat into the medium with the rate of change in temperature. The higher the thermal diffusivity, the faster will be the propagation of heat into the medium. All the coolants, except two, under investigation showed a significant increase in thermal diffusivity compared to pure water at lower coolant concentrations, gradually decreasing with increase in the coolant concentration. For efficient heat removal from the engine, the coolant must have a higher thermal diffusivity. Thermal diffusivity of water is 1.430×10^{-7} m^2/s and that of ethylene glycol is 0.938×10^{-7} m^2/s [14]. It can be seen from the measured data that for certain concentrations of first five coolants, the thermal diffusivity is increased beyond than that of water, which could not be explained without knowing the exact chemical composition of these coolants. However a decrease in thermal diffusivity with increase in the coolant concentration is not surprising, considering the fact that the thermal diffusivity of ethylene glycol is lower than that of water. Last two coolants showed a decrease in thermal diffusivity compared to water for all concentrations. Especially the thermal diffusivity of last coolant at two different concentrations is lower than that of pure ethylene glycol. This might be due to a completely different chemical composition of this coolant compared to others.

5. Conclusion

Transient thermal lens technique is quick and reliable method for the thermal diffusivity measurement and is also require a very small quantity of the sample. We have used only 0.3ml of the samples for the measurements. Our investigations show that care has to be taken while choosing the most suitable engine coolant and using it in the proper dilution recommended by the manufacturer. It is clear from our measurements that all good engine coolants shows an enhanced heat removal property compared to pure water, in addition to the other benefits such as anti-corrosion, anti-scaling and anti-foam properties as claimed by the manufacturers.

Acknowledgments

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References

1. William N M, editor. Engine Coolant Testing: Fifth Volume (STP1491). West Conshohocken: ASTM International; 2008.
2. Madhusree K, Dey T K. Thermal conductivity and viscosity of Al_2O_3 nanofluid based on car engine coolant. J. Phys. D: Appl. Phys. 2010; 43 (31): 315501-10.
3. Elias M M, Mahbubul I M, Saidur R, Sohel M R, Shahrul I M, Khaleduzzaman S S, Sadeghipour S. Experimental investigation on the thermophysical properties of Al_2O_3 nanoparticle suspended in car radiator coolant. Int. Comm. Heat and Mass Transfer. 2014; 54: 48-53
4. Bernal-Alvaradoa J, Mansanares A. M, da Silva E. C, and Moreira S. G. C, Thermal diffusivity measurements in vegetable oils with thermal lens technique, Rev. Sci. Instr. 74(1), 697, 2003
5. Long M E, Swofford R L, Albrecht A C. Thermal lens technique: a new method of absorption spectroscopy. Science. 1976; 191(4223): 183-185.
6. Dovichi N J, Harris J M. Laser induced thermal lens effect for calorimetric trace analysis. Anal. Chem. 1979; 51 (6): 728-731
7. Estupiñán-López C, Tolentino Dominguez C, and de Araujo R. E, Eclipsing thermal lens spectroscopy for fluorescence quantum yield measurement, Opt. Exp. 2013, 21, 18592-18601.
8. Gordon J P, Leite R C C, Moore R S, Porto S P S, Whinnery J R. Long Transient Effects in Lasers with Inserted Liquid Samples. J. Appl. Phys. 1965; 36(1): 3-8.
9. Dovichi N J, Harris J M. Time-resolved thermal lens calorimetry. Anal. Chem. 1981; 53: 106-109.
10. Gupta R, Theory of photothermal effect in fluids. In: Sell J A, editor. Photothermal investigations of solids and fluids, New York: Academic Press; 1988, p. 81-126.
11. Astrath NGC, Rohling J H, Medina A N, BentoA C, Baesso M L, Jacinto C, Catunda T, Lima S M, Gandra F G, Bell M J V, Anjos V. Time-resolved thermal lens measurements of the thermo-optical properties of glasses at low temperature down to 20 K. Phys. Rev. B. 2005; 71: 214202-6.
12. Marcano A, Loper C, Melikechi N. High-sensitivity absorption measurement in water and glass samples using a mode-mismatched pump-probe thermal lens method. Appl. Phys. Lett. 2001; 78: 3415-3417.
13. Venkanna B K, Fundamentals of Heat and Mass Transfer, PHI Learning Pvt. Ltd, New Delhi, 2010, (ISBN: 978-81-203-4031-2)
14. Lide D R (Editor), CRC Handbook of Physics and Chemistry, CRC Press, Boca Raton, FL,2005.

Optimization of an optical chopper-laser beam arrangement in low-frequency applications

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Abstract

Optical choppers are widely used in combination with continuous wave lasers in many spectroscopic and other materials characterization techniques. However, utmost care has to be taken in the use of an optical chopper in very low frequency applications. In this paper, we have used simple calculations to demonstrate the importance of the relative position of an optical chopper with respect to the laser beam path for minimal impact of the chopper speed on the measurements. We have also demonstrated an alternative simple, low-cost and easy to fabricate electromechanical shutter instead of a chopper for single pulse generation from a continuous wave laser. Focusing of the laser beam on the chopper blade can also minimize the adverse impact of slowly moving chopper wheel.

Keywords: Optical chopper, laser beam modulation, transient thermal lens,

1. Introduction

Optical choppers are a mechanical method of repetitively switching light beams, usually continuous wave laser beams, on and off. Rotating disc choppers, fixed frequency tuning fork choppers and optical shutters are different types of optical choppers, of which rotating disc choppers are widely used because of its frequency variable feature. Rotating disc choppers or popularly known as mechanical chopper consist of a slotted rotating metallic disc through which the light beam passes producing the chopping action [1-5]. Optical choppers are widely used in research labs, especially in spectroscopy experiments, in combination with other instruments such as lock-in amplifiers or digital storage oscilloscopes [6-13]. To be effective, an optical chopper should have a stable rotating speed. Maximum chopping frequency is limited by the motor speed and the number of slots in the rotating disc, which is in turn limited by the disc radius and the beam diameter. The chopping discs come in a variety of slot apertures and its operating frequency range varies from as low as 1 Hz to 10 kHz and typical frequency resolution varies from 0.01 Hz to 1 Hz [1-5]. Usually, the number of slots varies from as low as 2 slots to couple of hundred slots and to operate over a broad range of frequencies chopper blades should be changed, depending on the specified frequency range [1-5]. Maximum allowed diameter of the beam depends on the number of slots on the blades, higher the number of slots, smaller will be the beam diameter. The allowed beam diameter varies from less than a mm to more than a cm. For dual beam experiments, optical choppers are available with two different set of slots with different numbers of slots in the same chopper blade [1-3]. Typical diameter of commercially available optical choppers is in the vicinity of 10 cm [1-5].

If such a rotating blade mechanical chopper is used for very low frequency modulation of laser beams and if the subsequent detection is in the transient regime, then one has to carefully optimize the arrangement of the chopper to reduce its impact on the measurements. Transient thermal lens technique is an example in which mechanical choppers are widely used at very low frequencies for modulating continuous wave laser beams [14- 22]. Low frequency operation means slow rotational speed, consequently longer time for the chopper to completely block/unblock the laser beam.

In this paper we have calculated the effect of chopper speed, laser beam radial position on the chopper wheel and the laser beam diameter on the time required for the chopper slot to cross the laser beam. These parameters have great significance in low frequency applications of mechanical choppers, especially if the subsequent laser induced phenomena is in very short time scales. As an alternative to the slow rotating disc mechanical choppers, we have also demonstrated the superior performance of a simple, low-cost and easy to fabricate electromechanical shutter instead of a chopper for single pulse generation from a continuous wave laser.

2. Calculations

Rotating blade mechanical chopper operating at fixed frequency has constant angular velocity but the linear velocity is different at different radial distances. The wheel rotating with an angular velocity ω has a linear velocity $v = r\omega$, at distance r from the axis. The time, t, taken by the chopper slot edge to cross a laser beam of $1/e^2$ diameter d can be calculated using the relation $t = d/v$. This basic principle is used in our calculations. In research papers, generally authors mention the chopper frequency clearly but none report the radial position at which the laser beam pass through the chopper blade or the linear velocity of the chopper slot edge at the laser beam [14-22]. Since this information is not given by the authors, it is reasonable to assume that the importance of positioning of the laser beam on the chopper wheel is not taken into account. Without this information, the chopper frequency alone is not complete and adequate in understanding its impact in transient measurements such as transient thermal lens. This will be clear from the results discussed below.

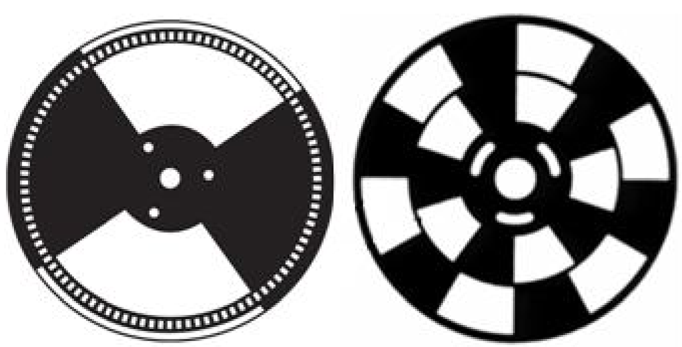

Figure 1*. Typical examples of chopper wheels for low frequency applications. (a) 2-slot chopper wheel (Thorlabs MC 2000), (b) dual beam 5/6-slot chopper wheel (Stanford Research Systems SR 540).*

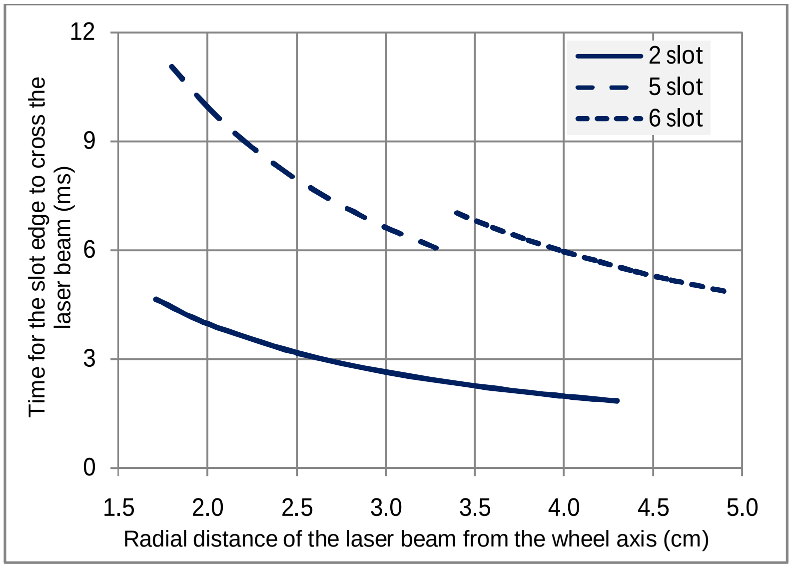

***Figure 2**. Time taken by the chopper slot edge to cross a 1mm diameter laser beam ($1/e^2$ diameter) for different radial positions of the 2-slot and 5/6-slot wheels when operated at 4Hz.*

3. Results and Discussion

For the calculations we have used two commonly used types of chopper wheels, 2-slot wheel and 5/6-slot wheel, designed for low-frequency operations. According to the manufacturers, the operating frequency of the Thorlabs MC2000 chopper with 2-slot wheel is 1Hz to 99Hz and Stanford Research systems SR540 chopper with 5/6-slots wheel is 4Hz to 400Hz (fig 1). The 2-slot wheel opening has inner radius of 1.71cm and outer radius of 4.3cm [1]. The inner 5-slots of the 5/6-slot wheel have an inner radius of 1.8cm and outer radius of 3.3cm and the outer 6-slots have an inner radius of 3.4cm and outer radius of 4.9cm [2]. Considering a typical $1/e^2$ beam diameter of 1mm of a diode pumped solid state (DPSS) laser and for a chopper frequency of 4Hz, the time taken for the chopper wheel slot edge to cross this beam versus radial position is calculated and shown in figure 2. Less slots means more number of rotations for the same frequency and as expected the 2-slot wheel is faster than the 5/6-slot wheel. But for the 5/6-slot wheel, the 6 slot outer layer is faster than the 5-slot inner layer. Note that we have used the radial distance of entire opening of the wheels in all these calculations. But in practice, due to the finite diameter of the laser beam, the beam can position at a distance less than that of the beam radius in all these calculations at two extremes of the wheel openings. That means, out of the full opening range of 1.71 cm to 4.3 cm of the 2-slot wheel only the range of 1.76cm to 4.25cm can be used for a 1mm diameter laser beam. One can see that the time taken for the chopper slot edge to cross the laser beam varies from few milliseconds to several milliseconds, which is not negligible if the modulated laser is used for transient investigations in which the transient mechanism itself is fast. In such situations a chopper should not be used for modulating or single-pulse generation through laser block/unblock operation. Instead, alternative methods suggested below should be used.

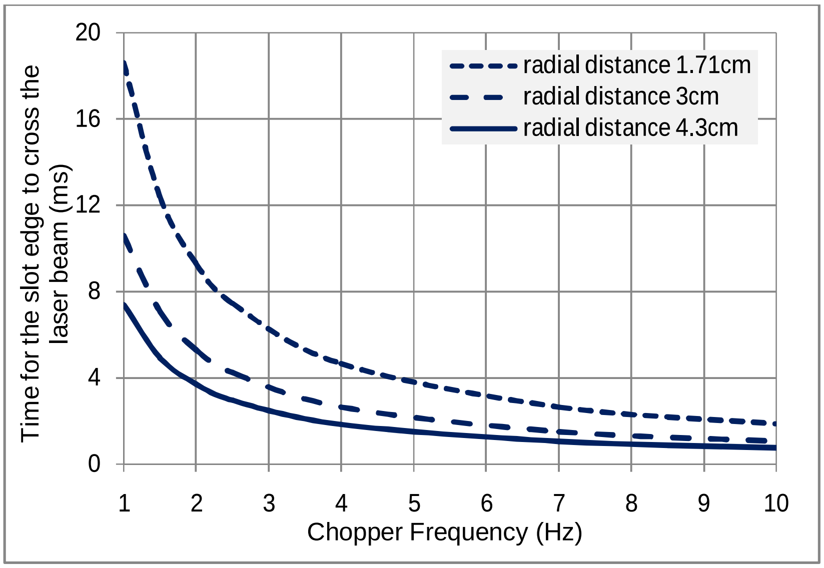

Figure 3*. Time taken by the chopper slot edge to cross a 1mm diameter laser beam (1/e^2 diameter) for different chopper frequencies by the 2-slot wheel. The three different lines show minimum, medium and maximum radial positions of the laser beam on the chopper wheel.*

Figure 3 shows the effect of chopper frequency on the time taken for the chopper wheel slot edge to cross a 1mm diameter laser beam at three different radial positions of the 2-slot wheel. It is clear that the impact is severe when the laser beam is closer to the axis. Also the effect is adverse at lower frequencies and as the modulation frequency increases, the time taken to cross the beam decreases with chopper frequency according to a power law relation with the modulation frequency. We have also investigated the effect laser beam diameter on the chopper wheel. Figure 4 shows the linear relationship of the beam crossing time on the laser beam diameter on the chopper wheel. Three different straight lines correspond to the data at two extreme radial positions and at the middle of the opening of the 2-slot wheel. The impact becomes severe when the laser beam diameter increases and the beam is positioned closer to the axis of the wheel. The time value becomes smaller and closer to each other for different radial positions when the laser spot becomes smaller. Hence the best method to keep the beam crossing time minimum for a given chopper speed is to focus the laser beam onto the chopper blade and position it closer to the outer edge of the wheel. Especially if the original laser beam is bigger in diameter, then focusing can be more tightly and hence crossing time can be reduced from several milliseconds to sub-milliseconds region.

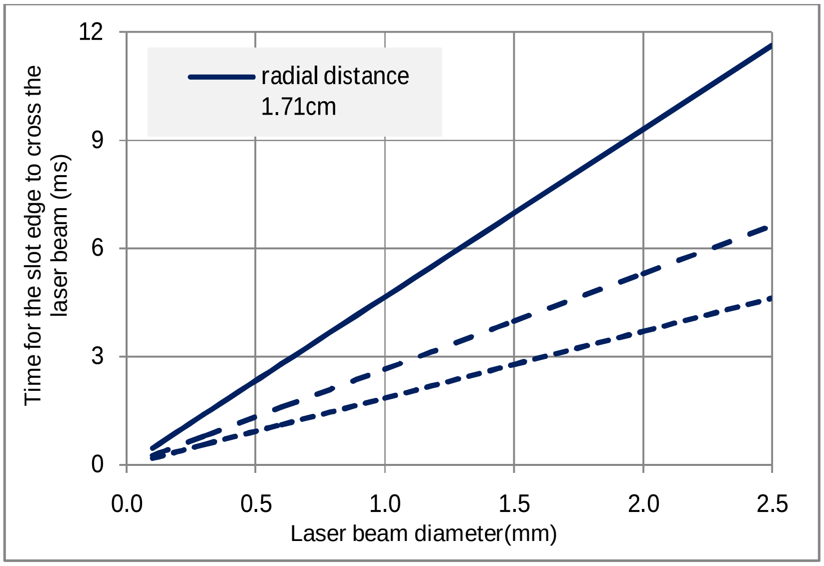

Figure 4. *Variation of the time taken by the 2-slot wheel edge to cross the laser beam as a function of laser beam diameter. The three different lines show minimum, medium and maximum radial positions of the laser beam on the chopper wheel. Laser beam diameter of 0.1mm corresponds to a tightly focused laser and 2.5 mm corresponds to an expanded/diverging laser beam.*

A simple, low-cost, and easy to fabricate optical shutter to block/unblock a laser beam is designed and tested. We have used a commonly available 9V electromechanical relay for this purpose. Cover of the relay is removed and a 15cm long and 0.5cm broad, thin aluminium sheet is attached to the moving arm of the relay using high performance glue. The relay is connected to a 9V battery through a switch. Laser beam is allowed to cross the arm near to its tip. Longer the arm, grater will be the linear velocity and shorter the time taken to block/unblock the beam. Typical relay switching time is of the order of several milliseconds. We have used a relay with a rated release time of 5ms but adding the long arm to the relay decreased the time to cross a 0.7mm diameter laser beam to 200 microseconds (figure 5). The laser beam is positioned close to the tip of the moving arm attached to the relay and the speed of the shutter is measured using a photodiode (Vishay Telefunken BPW20R). A digital storage oscilloscope is used to record the photodiode response while unblocking the beam by activating the relay using the switch. The performance of this simple shutter is much better than that of commercially available shutters used for modulating cw lasers in many studies [23-24].

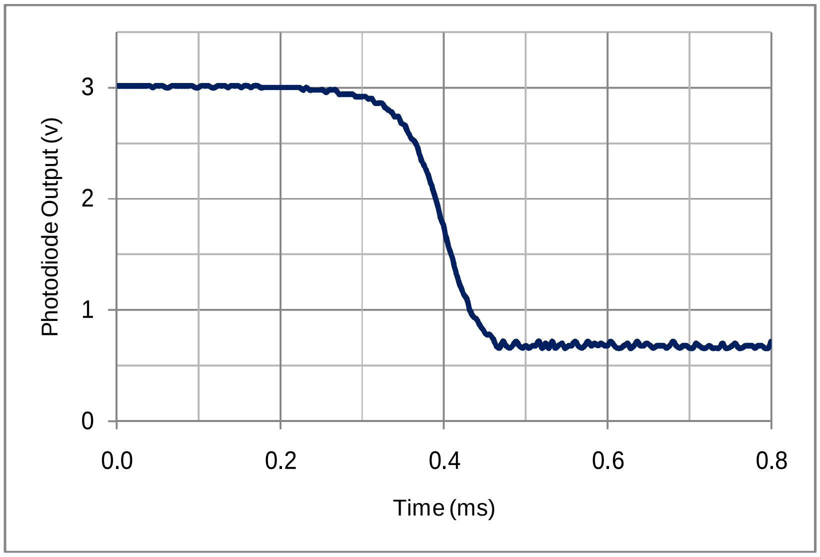

Figure 5. *Shows the switching speed of the assembled electromechanical shutter using a 9V relay.*

4. Conclusion

In conclusion, we have demonstrated the importance of careful positioning of a laser beam on a rotating disc copper wheel in measurements where the temporal pulse shape is very important. It is recommended to position the laser beam at the extreme radial position of the opening of the chopper wheel and use a chopper wheel with minimum number of slots. For low frequency applications, it is recommended to use the "highest possible low frequency" and focusing the laser beam onto the chopper wheel produce sharper pulse edges. For single pulse laser on/off applications, instead of an expensive chopper, a simple and low-cost electromechanical shutter can be assembled and the performance of which is superior to that of a low frequency chopper operation.

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References

1. Thorlabs MC2000 optical chopper system, <http://www.thorlabs.com/thorproduct.cfm?partnumber=MC2000> Last Accessed on 2/9/2014
2. Stanford Research Systems SR540 optical chopper system, <http://www.thinksrs.com/products/SR540.htm> Last Accessed on 2/9/2014
3. Newport 3502 optical chopper system, < http://www.newport.com/Phase-Locked-Optical-Choppers/917676/1033/info.aspx> Last Accessed on 2/9/2014
4. Bentham 218M optical chopper module, < http://www.bentham.co.uk/218m.htm> Last Accessed on 2/9/2014
5. Holmarc HO-IAD-OC-01 optical chopper system, < http://holmarc.com/optical_chopper.php> Last Accessed on 2/9/2014
6. I Bhattacharyya, S Priyadarshi and, D Goswami , Molecular structure-property correlations from optical nonlinearity and thermal-relaxation dynamics, Chem. Phy. Lett. 469 (2009), 104–109
7. K Nakanishi, T Imasaka, N Ishibashi, Thermal lens spectrophotometry of phosphorus using a near-infrared semiconductor laser, Anal. Chem., 57 (1985), 1219-1223
8. A O Marcano, C Loper, N Melikechi, High-sensitivity absorption measurement in water and glass samples using a mode-mismatchedpump-probe thermal lens method, App. Phy. Lett., 78 (2001), 3415-3417
9. J Georges, Continuous-wave-laser versus pulsed-laser excitation for crossed-beam photothermal detection in small volume applications: comparative features, Appl. Spectrosc. 59(9) (2005) 1103-1108
10. B Bohnert, W Faubel, H J Ache, Use of photothermal deflection spectrometry (PDS) for studies of analytes in aqueous solutions, Fresenius' J. Anal. Chem., 338 (1990) 695-698
11. G A López-Muñoz, J A Pescador-Rojas, J Ortega-Lopez, J S Salazar and J A Balderas-López, Thermal diffusivity measurements of spherical gold nanofluids of different sizes and concentrations, Nanoscale Res. Lett. 7 (2012) 423-428
12. T Hinoue, J Kaji, Y Yokoyama and M Murata, Photopyroelectric spectrometry and its application to the determination of trace constituents in natural water, Anal. Chem., 63 (1991) 2086-2090
13. B Pathrose, V P N Nampoori, P Radhakrishnan and A Mujeeb, Measurement of absolute fluorescence quantum yield of basic Fuchsin solution using a dual-beam thermal lens technique, J Fluoresc. 24(3) (2014) 895-898
14. A V Brusnichkin, D A Nedosekin, M A Proskurnin, and V P Zharov, Photothermal lens detection of gold nanoparticles: Theory and experiments, Appl. Spect. 61 (2007) 1191-1201
15. N G C Astrath, J H Rohling, A.N Medina et.al.,Time-resolved thermal lens measurements of the thermo-optical properties of glasses at low temperature down to 20 K, Phys.Rev. B, 71, (2005) 2142021-6
16. J Slaby and F Träger, Sensitivity enhancement in thermal lens laser spectrometry, Appl. Phys, B, 54(6) (1992) 538-543
17. L R P Kassab, R A Kobayashi, M J V Bell, A P Carmo and T Catunda, Thermo-optical parameters of tellurite glasses doped with Yb^{3+}, J. Phys. D: Appl. Phys. 40 (2007) 4073–4077
18. S M Lima, J A Sampaio, T Catunda, et.al, Spectroscopy, Thermal and Optical Properties of Nd^{3+} Doped Chalcogenide Glasses, J. Non-Crystalline Solids, 284 (2001) 274-281
19. M R R Gesualdi, C Jacinto, T Catunda, M Muramatsu and V Pilla, Thermal lens spectrometry in pyroelectric lithium niobate crystals, Appl. Phys. B, 93 (2008) 879-883
20. D N Messias, C Jacinto, M J V Bell, and T Catunda; Thermal and Optical Properties of $Yb^{3+}$and Nd^{3+} Doped Phosphate Glasses Determined by Thermal Lens Technique, IEEE J. Quant. Electr. 43(9) (2007) 751-757
21. E O Serqueira, N O Dantas, G H Silva, V Anjos, M J V Bell, and M A Pereira-da-Silva, Thermal diffusivity of a SNAB glass system doped with CdS nanocrystals and Nd^{3+}, Chem. Phys. Lett., 504 (2011) 67-70
22. A N Iwazaki, V Pilla, V M Dias, E Munin, and A A Andrade, Self-Induced Phase Modulation for Thermo-OpticalCharacterization of Annatto Extracted Using Different Solvents, Appl. Spectros., 65(12) (2011) 1393-1397
23. C D Tran, S Challa, and M Franko, Ionic Liquids as an Attractive Alternative Solvent for Thermal Lens Measurements, Anal. Chem., 77 (2005) 7442-7447
24. O S Are´stegui, P Y N Poma, L S Herculano et. al., Combined Photothermal Lens and Photothermal Mirror Characterization of Polymers, Appl. Spectros. 68(7) (2014) 777-783

Signature of the Principal Investigator

PRINCIPAL (Seal)