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Aging resistance of laser protective filters

Rico Bühring[a,*], Winfried Janßen[b], Hans-Joachim Krauß[a]

[a]Bayerisches Laserzentrum GmbH (blz), Konrad-Zuse-Straße 2-6, 91052 Erlangen, Germany
[b]Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Friedrich-Henkel-Weg 1-25, 44149 Dortmund, Germany

Abstract

Various influencing factors concerning the laser resistance time of laser protective filters have already been studied, but the influence of the age of the filters not yet. Therefore, the main objective of this project is to investigate laser resistance time and optical properties spectral transmittance, luminous transmittance and diffusion of light versus the aging of laser protective filters. For measuring the resistance time experimental setups were realized to detect transmitting laser radiation behind the protective filters while performing laser resistance tests according the norm EN 207. These laser resistance tests were carried out with cw (continuous wave) and pulsed Nd:YAG laser sources at 1064 nm as well as a CO_2 laser at 10600 nm in cw- and pulsed mode. For the studies standard filter materials were artificially aged by UV-radiation. The experimental results were compared to the results for new (unaged) filter materials. Besides the effects of artificial aging, natural aging of filters was examined, as well.

Keywords: laser protective filters; aging effects; laser resistance test; laser resistance time

1. Motivation

The correct selection of laser protective goggles is essential for safe experimental work in laser laboratories and for maintenance work at laser systems in industry. The main task of the protective filters is to keep the irradiation at the eye below the Maximum Permissible Exposure (MPE) [1]. When laser protective goggles are getting older, it gets more difficult to decide if they still can be used, which means whether they still fulfill the requirements to their protective function. In research work the influence of the beam diameter on the laser resistance of protective filter materials was investigated [2], but not yet the effects of aging.

With the revision of the testing norm EN 207 [3] in the year 2010 a stability test to ultraviolet radiation was introduced for protective filters. The optical properties of filters after ultraviolet irradiation shall not change to such an extent that they can no longer fulfil the requirements of norm EN 207. Therefore, the spectral transmittance (optical density OD), luminous transmittance and diffusion of light are assessed by the certifiers before and after the exposure of the filters to ultraviolet radiation. But acc. to norm EN 207 it is not required to measure the resistance of the filters to laser radiation after being exposed to UV light, again. Thus, no information of the impact of ultraviolet radiation, i.e. of aging effects on the laser resistance of laser protective filters, is available. The consequence is that it belongs to the user of laser safety goggles to decide whether the googles after several years in use are still safe or should be replaced by new goggles. Even for the manufacturers of laser safety goggles it is difficult to give recommendation for the lifetime of their products.

Therefore, it is the aim to get a more detailed knowledge about the laser resistance of artificially and natural aged laser protective filters to laser radiation in order to estimate the lifetime of laser safety goggles.

2. Experimental setup

Testing the resistance of laser protective filters to laser radiation is carried out following the current issue of norm EN 207. Irradiation of protective filters is performed with specified wavelengths, power and energy

* Corresponding author. Tel.: +49-9131-977900 ; fax: +49-9131-9779011.
E-mail address: r.buehring@blz.org

densities according to the scale number of the filters. The diameter d_{63} of the laser beam during the laser resistance tests is defined to 1.0 mm.

To determine the laser resistance time of laser protective filters different laser types were used. Mainly a cw lamp-pumped Nd:YAG laser “QY1000D” (wavelength 1064 nm) from Haas-Laser was applied. Its experimental setup is shown in Fig. 1. The laser protective filter is placed according to the measured caustic of the laser beam in such distance from the focusing optic that the required beam diameter d_{63} of 1.0 mm is realized on the surface of the filter. Behind the filter, in a distance of 30 mm, a blackened photographic paper is placed to detect transmitting laser radiation. The required laser power is adjusted at the operation unit of the laser and controlled by using a power meter head LM 200 from Coherent. As the airflow has an influence on the laser resistance tests, the local exhaust ventilation is always placed 250 mm above the point of laser impact to have constant conditions for a high reproducibility of the tests. A shorter distance would cause a heavier reaction of the laser beam with the protective filters caused by feeding the reactive zone with fresh oxygen, which could result in shorter resistance time of the filters.

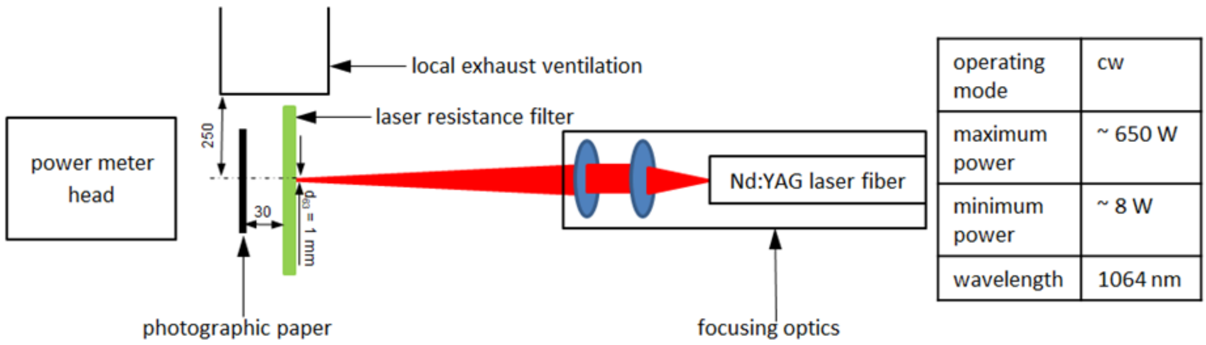

Fig. 1. Schematic setup for detecting the laser resistance time T of laser protective filters using a cw Nd:YAG laser.

The experiment starts with the laser beam switched on and a stopwatch being actuated. The time is stopped as soon as a visible effect on the blackened photographic paper placed behind the irradiated filter can be seen (failure criterion). This measured time between start and end of the experiment defines the laser resistance time T of the tested laser protective filter and is the comparison criterion for possible aging effects. The parameters for the laser resistance tests, i.e. the suitable laser power, which lead to reasonable laser resistance times, were determined in preliminary tests or set in relation to the certified scale number of the filter.

Furthermore, a pulsed Nd:YAG laser “HL 204 P” (wavelength 1064 nm) from TRUMPF and a CO_2 laser “Microstorm” (wavelength 10600 nm) from FEHA LaserTec, that was used in its cw and also its pulsed mode, were applied for the tests. The experimental setups are comparable to that of the cw Nd:YAG laser shown in Fig. 1.

The laser resistance tests described above were done with artificially aged laser protective filters based on Polymethylmethacrylate (PMMA) and Polycarbonate (PC), which are the most common matrix materials for laser protective filters, and with naturally aged filters that were in use for more than 10 years. The artificially aging was done with UV radiation, using a xenon high-pressure lamp with a power of 450 W (Osram). The first set of six filter samples was aged for 50 h. A second set of six filter samples was aged for 200 h. The third set of filter samples wasn’t aged and was used for comparative tests. Aging for 200 h with ultraviolet radiation corresponds to several years of storing the filters permanently in direct sun light. With all samples in their initial status (i.e. in their unaged status) the spectral transmittance (OD), the luminous transmittance and the diffusion of light were measured according norm EN 207. These measurements were repeated after exposure of the first and second set of filters to ultraviolet radiation. After aging and detection of these optical properties all sets of samples were tested to their resistance to laser radiation until failure and the laser resistance time T was measured as described above. The natural aged filters were tested to their laser resistance in comparison to new filters of the same product if still available. Natural aged filters, that were no longer available as new products on the market, were tested to their laser resistance concerning the certificated scale number. The optical properties like spectral and luminous transmittance were measured also on the natural aged filters in comparison to the new products.

3. Results and discussion of the experimental work

The experimentally detected laser resistance time T versus the aging condition of the artificially aged PMMA filters at 1064 nm and 10600 nm is shown in Fig. 2. These experimental results demonstrate a similar correlation between the laser resistance time and the aging condition for both wavelengths. It can be seen that artificial aging of PMMA filters by ultraviolet radiation leads to a moderate loss of laser resistance. For the Nd:YAG laser radiation at 1064 nm the laser resistance time decreased for around 10 % and for the CO_2 laser radiation at 10600 nm for around 13 %. For comparison, the used PMMA filters are certificated with a scale number of D LB6 at 1064 nm, which means that these filters withstood an irradiation with a laser power of 7.9 W at a beam diameter d_{63} of 1.0 mm for at least 5 s. In our study we have shown that the real laser resistance of the tested PMMA filters at 1064 nm is even higher. The filters, even which were aged for 200 h, withstood laser radiation at a power of 30 W for around 28 s. Thus, the detected decrease of laser resistance time of 10 % after aging for 200 h means a protection level, which is well beyond that of the certified scale number. Therefore, the loss of laser resistance with aging time seems not to be the limiting factor and is negligible for the investigated conditions. Since aging for 200 h with ultraviolet radiation corresponds to several years of storing the filters permanently in direct sun light, one can assume, that laser safety goggles with PMMA filters used within their certified range could withstand exposure to laser radiation even after years of use.

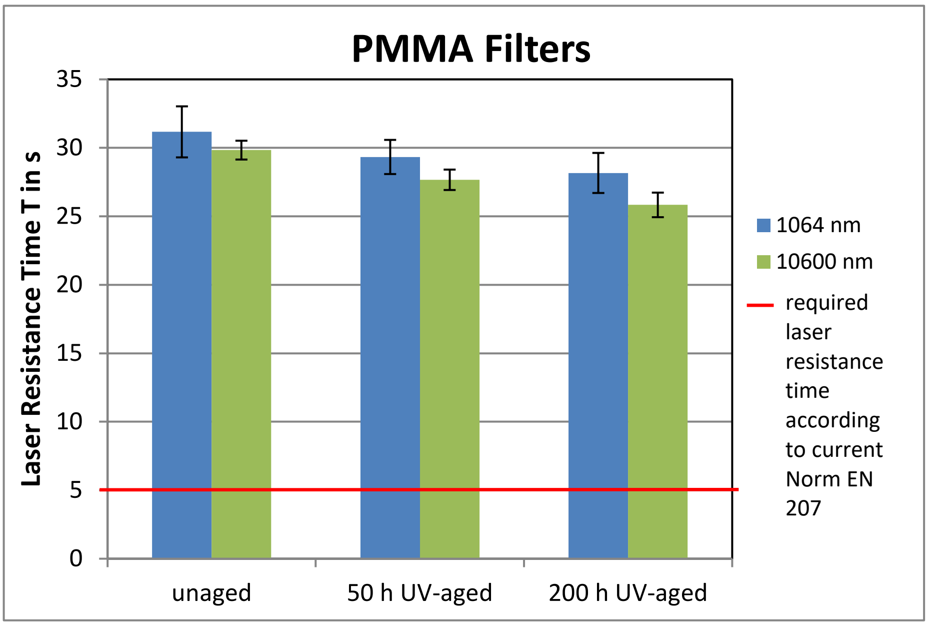

Fig. 2. Laser resistance time T versus aging state of the PMMA filters tested with Nd:YAG laser radiation at 1064 nm and CO_2 laser radiation at 10600 nm (average value out of six measurements).

Although the laser resistance seems not to be the limiting factor, aging shows effects on the optical properties of the PMMA filters, which could make the use of the goggles critical. The measurements for the spectral transmittance (OD) show no measurable decreasing of the values by aging, because the values are still above the upper limit of the measuring range of the used spectrometer. That underlines the results that laser resistance time is not decreasing significantly with the age of the filters. The situation differs for diffusion of light, where the limit value is 0.5 $cd/m^2/lx$. PMMA filters aged for 200 h by ultraviolet radiation show a diffusion of light around this limit value or slightly above it, what might be recognized by the user of the laser safety goggles. The maximum acceptable decreasing of the luminous transmittance after 50 h UV radiation concerning the norm is 10 %. The measured luminous transmittance on the PMMA filters aged for 200 h are just in the tolerance range given by the norm.

In contrast to the PMMA filters, a systematic investigation of the laser resistance at PC filters at 1064 nm and 10600 nm was not possible, because PC could be tested only sporadically until failure. During the laser resistance tests, next to a heavy appearance of smoke and flames, the filter material was carbonized by the laser beam (Fig. 3). Therefore, no transmitting laser radiation could be measured within a meaningful time period and the tests needed to be stopped. So all tested artificially aged PC filters have reached there certificated scale number or were even well beyond. Concerning the optical properties of artificially aged PC filters, no influence of aging could be measured.

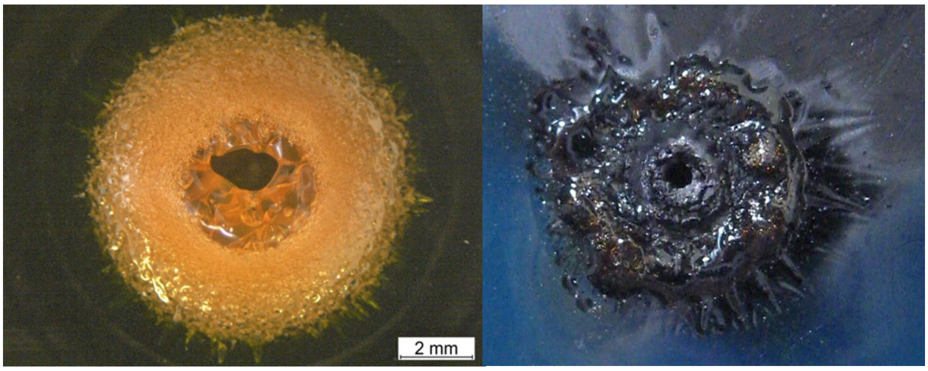

Fig. 3. PMMA (left) and PC (right) laser protective filter tested with Nd:YAG laser radiation at 1064 nm.

For all natural aged laser protection filters, which were still available as new products on the market, the measured laser resistance times at 1064 nm were on the same level as for the new filters. Moreover, the found laser resistance time was often even much higher than the requirement concerning the current issue of the norm EN 207. At the filters tested with CO_2 radiation at 10600 nm, no difference in the behavior of the old and new filters could be detected. Both filters exceeded the requirement according EN 207. The laser resistance tests at natural aged filters without availability of corresponding new products show that all filters, even after 20 years in use, reached their certified D-scale numbers at 1064 nm and 10600 nm or achieved even much better results.

With regard to the optical properties no critical chance of the optical density of the investigated natural aged filters could be determined. Furthermore, the luminous transmittance showed no significant degradation of the values of the old filters compared to the new filters. And finally all natural aged filters observed within the project did not exceed the limit for the diffusion of light.

4. Conclusion

The data obtained from described experiments with Nd:YAG and CO_2 laser radiation have led to the result that aging is not a limiting criteria concerning the laser resistance of artificially aged PMMA and PC filters. Even after 200 h under UV-radiation, which corresponds to aging for several years under direct sun light, only a negligible decrease of the laser resistance could be seen. And the laser resistance time was well beyond the requirement defined by the testing norm EN 207. Only in case of artificially aged PMMA filters the values of the luminous transmission reached the limits from the testing norm EN 207 and the diffusion of light was partially beyond the limits from the norm.

A positive result could also be found with the investigations on natural aged filters. The tested old filters show a laser resistance that was equal to that of new filters from the same product. No critical decrease of that protection level could be found. Old filters without an available identical new product have not only reached their certified D-scale numbers concerning laser resistance at 1064 nm and 10600 nm, but are mostly well beyond that level. The optical properties of the old filters are no critical point concerning aging because they show just a negligible decrease of the values compared to the values of the corresponding new products.

Finally, the investigations made at standard laser filter materials have shown no safety relevant aging effects. In addition, when wearing laser safety goggles, user should pay more attention to the apparent condition and possible mechanical damage of the goggles than just to their age.

Acknowledgements

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