Implementation of Advanced Alignment Algorithms for High Precision Optical Components

C. Brecher, T. Mueller, N. Pyschny, S. Haag
Fraunhofer-Institute for Production Technology IPT, Germany

tobias.mueller@ipt.fraunhofer.de

Abstract

Nowadays the production of optical systems such as Optically Pumped Semiconductor Lasers (OPSL) is dominated by manual assembly operations. Automated solutions have been demonstrated in the recent past. Nevertheless, automated alignment processes do not occur in industry, as alignment tasks are complex leading to limited robustness, speed and reproducibility. Furthermore the implementation of automated assembly processes is connected to significant effort. The development of advanced alignment algorithms, easily implementable for an efficient setup of automation solutions is a potential answer to the economic challenges laser manufacturers are facing in laser setup development. In the course of the "SCALAB"-project, funded by the Federal Ministry of Education and Research (BMBF), a process development setup was developed. Research activities covered hardware, software and process development. This paper will describe the nature of two alignment process development approaches to tackle these challenges, exemplary for the alignment of a resonator mirror (HR-mirror) utilizing a flexure based micromanipulator, a beam profiler and an optical power meter.

1 Active Alignment of resonator end mirror

The alignment of the resonator end mirror of an OPSL is one of the most sensitive steps in this specific laser assembly. The resonator is formed by the OPS face (OPS), a folding mirror and a highly reflective end mirror (HR-mirror). The HR-mirror is the final component to be mounted. In prior steps the OPS and the folding mirror are passively aligned and mounted. Since these three components form a resonator, the HR-mirror's final orientation will be dependent on the specific orientation/position of the OPS and the folding mirror. As a consequence, the final HR-mirror orientation can only be determined in an active alignment, since passive alignment operations will only achieve a limited precision and the compensation of prior misalignments of OPS and folding mirror will not be possible with other alignment strategies.

For the alignment of the HR-mirror, a measurement setup was setup. The OPSL beam was split in order to measure the output power and the beam profile. For this purpose a beam sampler was used, which reflects only 1% of the beam to the beam profile and lets the rest pass through. After this beam sampler the main beam was filtered, to reflect the wavelength of the pump laser, and then focused to the power meter head. Figure 1 shows the physical layout of the components in the alignment setup.

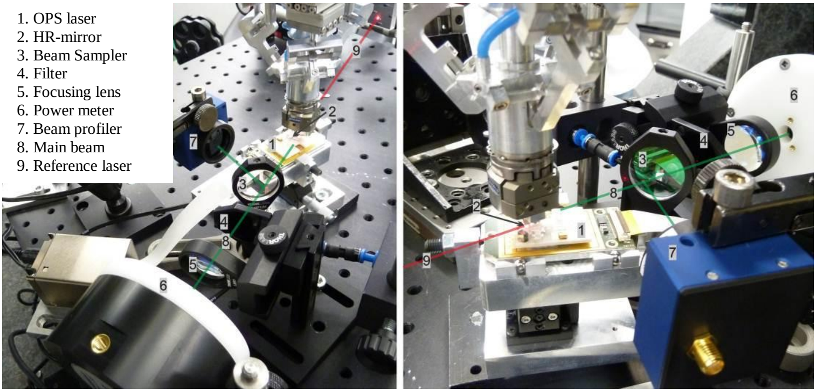

Figure 1: HR Mirror Alignment Setup

1.1 Finding the operating coordinates

Finding the optimum coordinates for maximum output power is a two-stage process For both stages the developed approaches of the alignment algorithms are dependent on the particular laser behaviour to different misalignments of the HR-mirror. In order to design alignment algorithms for the OPSL, a sensitivity analysis of the laser output power to misalignments in the HR-Mirror has to be performed to define search process parameters such as step-width, step number and optical output threshold.

The first step is a spiral-shaped binary search. The search covers a large area to find an HR-mirror orientation where the resonator starts to have an effect in the output power of the laser. The second and final step is a stochastic algorithm approach for global optimization of the output power based on the simulated annealing (SA) method, which has demonstrated robustness, time-efficiency and high success rates. The SA is a methodology, well-known in Informatics technologies. SA is a generic probabilistic metaheuristic for global optimisation problems. Especially advantageous of this method is its efficiency in comparison to exhaustive enumeration approaches, when not the best, but an acceptable solution is to be determined[1]. The approach is rather simple: From the starting point a new coordinate is selected randomly with a previously determined distance from the starting point and optical power is measured. If the output power is above the starting point value, these coordinates are being kept. In case of a lower value, new coordinates, opening an angle of 120° between starting point and first measurement point, are being tried. These steps are performed until the next is reached. Also break criteria, being either a threshold value or break condition regarding the amount of measurements producing no higher values are possible. In Figure 2 both active alignment steps are explained graphically.

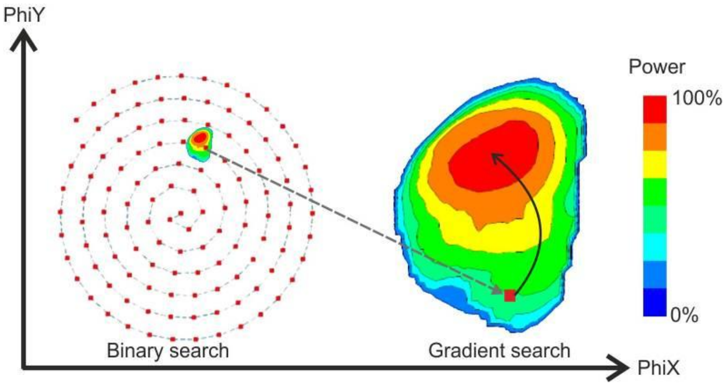

Figure 2: Active alignment procedures; left: Spiral search; right: Simulated annealing

2 Results

The active alignment process of the HR-mirror as the final component of an OPSL has been successfully implemented. Assembly times including bonding have been reduced to less than two minutes, compared to approximately 10 minutes at manual assembly. The process is subdivided in two consecutive steps. The success rate for the binary search algorithm is at 100% in an area of ± 0.8° in both X- and Y-direction. Between 3 and 19 sampling points are necessary to find the operating

[1] Simulated Annealing: Theory and Applications, P.J. van Laarhoven, 1987

coordinates. The alignment time results from the multiplication of necessary sampling points and sampling time (in this case 1 second) and can be given with < 20 seconds. The average alignment time in the performed experiments was 10.25 seconds. Consequently, starting at these operating coordinates the power maximization using a simulated annealing routine is the second and final alignment step. A success rate of 100% was achieved for procedures performing 40 steps or more, resulting in alignment times of 40 seconds. The alignment time is proportional to the power meter sampling time once again.

3 Conclusion and outlook

This active alignment procedure is just one example for automated assembly processes which have been realised in the "SCALAB" project[2]. Process development time has been minimised due to the flexible approach. It has been shown, that the simulated annealing algorithm is suitable for the alignment of laser resonators. Robustness, effectiveness and alignment capabilities of the algorithm have been demonstrated successfully. Prospectively the process development concept developed in the course of the project can potentially change the situation of laser manufacturers fundamentally as automated processes make their way into laser manufacturing industry.

4 Acknowledgement

We would like to thank the German Ministry for Education and Research (BMBF) for supporting this work by funding the project SCALAB (Scalable Automation for emerging Lab Production) within the mnt-ERA.NET program.

5 References

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[2] SCALAB - Scalable Automation for Emerging Lab Production: Final Report