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OPPONENT'S OPINION OF DOCTORAL DISSERTATION

Ing. Minh Tuan Pham

,,LASER WITH NARROW SPECTRAL LINEWIDTH FOR METROLOGY OF LENGTH‘‘

The submitted dissertation “Laser with Narrow Spectral Linewidth for Metrology of Length” of Ing. Minh Tuan Pham deals with the topic of spectral and temporal stabilization of narrow bandwidth CW laser system. This is a highly actual topic with many potential applications in spectroscopy, time synchronization, construction of atomic clock, quantum computing and other highly accurate applications in metrology. The author focuses in the thesis on several techniques of emission line narrowing in order to be able to excite specific transitions of cooled $^{40}Ca^{+}$ ions. This requires extremely narrow linewidth laser system emitting at 729 nm which approaches bandwidth as low as several Hz. Reaching of such parameters is extremely difficult and even in case of success, such a laser is very sensitive to all temperature changes and mechanical disturbance. Therefore, it must be operated in isolated and stable environment. All together makes the task technically challenging and the investigator must prove ability to solve multidisciplinary tasks in the field of classical and quantum optics, electrical engineering, mechanical engineering and programming.

The PhD thesis has 120 pages in total. It is divided into 2 sections. The first one is descriptive and comments on motivation, state-of-the-art, and problems solved by the author during his PhD. The second one is a commented collection of author’s scientific papers published during the PhD study. The first section has 71 pages and comprises introduction, 5 descriptive chapters and conclusion. The individual chapters describe fundamentals of optical atomic clock, requests for the spectroscopy laser, overview of laser emission line narrowing techniques, author’s original experimental solution of the laser stabilization and the spectroscopic setup, and, finally, a summary of spectroscopic experiments on calcium ions. The second section has 48 pages including, besides the reprints of papers, 8-pages-comments on the papers and summary of author’s contribution to the papers. The thesis is written in a brief form, which is sometimes at expense of clarity and exactness, however, it contains all essential sections and describes well author’s motivation and methodology of the research. In addition, all novel results are comprehensively summarized in the extensive appendix containing reprints of three scientific papers relevant to the thesis. Only one of them is published by Ing. Pham like the first author, however, his contribution to other ones seems to be significant as well. The thesis is written in English language at high language quality level, however, it contains significant number of typos (even in the thesis title) and other formal inaccuracies. Position of figures in the thesis is also frequently far from the figure reference in the text, which makes the thesis more difficult to read. Because of the formal mistakes I recommend to the author one more proof-reading of the thesis.

The author follows all methods of exact scientific work based on hypotheses and experimental evidence. Implementation of the individual tasks of the research is clearly described in the dissertation, both in the descriptive section, and the papers reprints. The author systematically analyzed theoretically and

experimentally several different solutions of the spectroscopy laser problems. The most suitable solution is realized, including problems of thermal and vibrational analysis and isolation, and programming of a control code for the setup. Functionality of the setup is proven by several spectroscopic experiments on calcium ions. Novelty of the solution is proven by the reviewed publications in impacted journals. The author has thus demonstrated the ability to independently and systematically solve complex scientific tasks, and so qualified for the scientific degree Ph.D.

To conclude, the submitted dissertation of Ing. Minh Tuan Pham can be considered like an original and highly actual one. All his research was done at professional level. This is supported by numerous peer-reviewed publications and contributions at scientific conferences.

I therefore recommend acceptance of the thesis for defense and awarding Ing. Pham Ph.D. degree in case of successful defense.

Additional questions and comments on the thesis

I suggest to clarify following questions during the defense:

1) In chapter 1.2 is a problem with figure references – ref. to fig.1.3 should probably be ref. to figure 1.2, figure 1.2 and 1.4 have no reference in the chapter at all. In the Fig. 1.3 is no explanation why the C_2H_2 box is in the setup.
2) Page 15 last paragraph – it is not clear how the polarization should be adjusted, the text is confusing or wrong
3) Page 16, 1.3.1 3rd paragraph – $S_{1/2}$ should be the lowest level, there might be a mistake in the sentence $S_{1/2}$ level decays …
4) In your feedback loops were used several PIDs (e.g. fig.3.1, fig.4.1). How were constants of the PID selected to prevent oscillations and other unwanted effects?
5) Which kind of photodetector was used in the setup according to the fig.3.1 (PD1)?
6) In chapter 3.1 is no reference and explanation to the fig.3.2. Why the grating was used? To separate spectral components? How it was correctly aligned?
7) Eq. 3.1 – what means f_{tau}
8) Fig. 3.4 does not show FWHM of both the curves
9) Page 37, 1st paragraph – author claims he concludes that the best stabilization technique is locking to an ultrastable cavity. Why? Explanation and some data are missing.
10) Can you better explain how the fiber noise cancellation unit (AOM3) works? Which kind of noise you need to compensate and what is bandwidth of the module?
11) Is there any plan for the further line narrowing from tens of Hz to the desired 1 Hz?

In Prague, February 2, 2023

Ing. Martin Smrž, Ph.D.
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