Review on

the Dissertation of Mr. MSc. Wojciech BUESCHKE

Experimental identification of an engine lean burn gas-air combustion system with turbulent jet ignition

Mr. Wojciech Bueschke has conducted research on the ignition of gas engines, as gas engines are probably becoming more important in future due to lower emission and higher availability of natural gas compared to liquid petrol fuel. Ignition is more difficult due to the lower ignitability essentially of methane.

Mr. Bueschke has compared the direct spark ignition with the turbulent jet ignition (scavenged prechamber spark ignition). The latter approach is currently becoming more common for very large engines which are operated at lean gas mixtures, while so far the smaller gas engines for cars are operated at stoichiometric conditions with the conventional (or an improved) spark plug ignition, as here the common exhaust gas treatment with the cheap three-way catalyst can be used. However, raw emissions of NOx would be lower for lean mixtures and the efficiency would be higher due to lower flame temperatures and lower heat losses to the walls. However, here the ignition is critical for the conventional spark plug ignition. So the topic of this thesis deals with the application of the alternative turbulent jet ignition. In so far the topic is of actual interest.

Mr. Bueschkes work was experimentally on a rapid compression machine (RCM) with optical access where either a spark ignition system (chapter 7) or a scavenged prechamber ignition system (chapter 10) has been applied. Also some experiments on a single cylinder real engine have been conducted (chapter 12).

So far so good.

However, the supplied version the thesis is difficult to be reviewed. As a reviewer I feel myself more in the role of a corrector as the English language is not satisfying, or as a detective, as the order of the experiments is only partly clear and the combination between the different experimental setups (in Chapter 6) and the results (in the Chapter 8 to 12) is often even not mentioned. The thesis needs certainly another round of rework until it would be understandable by itself. In an attachment - as well as in my version I give some proposals for rework.

My following review of the thesis is based on the assumption that the written text is corrected, trying to review only the content.

Chapter 1 and 2 introduces the topic and formulates questions, mainly that if the ignition of lean gas-air mixtures can be extended. In Fig. 2.1 the approaches of the thesis are listed. This part is good and sounds logically organized.

The idea of the approach seems to be:

- Firstly to identify the lean ignition limit as it is (with spark ignition). The experimental setup is described in Chapter 6.1 - the results in Chapter 7
- Secondly, to describe ignition phenomena for the prechamber (here especially of the mixing (Exp. Setup in 6.2 - Results in Chapter 8)) and of a conventional spark plug (Exp. Setup in 6.3 - Results in Chapter 9).
- Thirdly, to measure now lean ignition limits with the prechamber ignition system (Exp. Setup 6.4 - Results in Chapter 10).
- Fourthly, to investigate the combustion in a real engine with the prechamber ignition system (Exp. Setup in Chapter 6.5 - Results in Chapter 11).

For the reader later this switching between the chapters with experimental setup and results is difficult - but if Mr. Bueschke would help at the beginning of each chapters 7 - 11 what was the question here and where the experimental setup is described, then the reader would be able to follow.

Chapter 3 describes the state of the art of different ignition systems and chapter 4 that of different prechamber ignition experiments. The literature includes actual work.

Chapter 5 deals with optical measurement approaches for internal combustion engines, with scattering / laser induced fluorescence / schadowgraphy and schlieren / chemiluminescence and some of the literature.

Chapter 6 describes then the used experimental setups - as mentioned above. Essentially the rapid compression machine of the Institute is central here, which allows optical access. Some more back reference to the questions which shall be addressed (Chapter 2) would allow the reader more to understand why which setup is used. The purpose of chapter 6.6 is not clear to me as the header implies something different than the content.

The main result chapters 7 to 11 describe the different research results - but the tasks and which setup was used is certainly out of the memory of the reader. So each of this chapters should start with that (including the back references to the relevant chapters 2 and 6.x). In chapter 7 the aim seems to be to describe the conventional spark plug ignition with the ignition limits for lean mixtures. Without the motivation, why this is described here, it would be like a description of a student lab study with very expected results and some images of evolving flame kernels. If the motivation would be given, this results would appear much better.

Chapter 8 describes the mixing inside a specially build optical preignition chamber. Again the motivation and the setup need to be included. Then it could be clearer that these measurements eventually are the first in the world being done inside an optical preignition chamber (Question: is that the case ?). And the main results would not just be like "higher injection pressure increases the mixing process, higher chamber pressure ex-

tends the mixing process" - but would be a direct confirmation of this probably expected result.

Chapter 9 describes the phenomenology of conventional spark plug ignition (header has a mistake). The investigator uses his nice high speed camera setup to visualize these processes. However, I would believe that such measurements outside an engine are already often done. Motivation is so far not fully clear to me - but the author could clarify that probably.

Chapter 10 seems to be central and essentially new. Again the reference to the experimental setup and the used measurement techniques should be given at the beginning. Also the reference which questions are addressed.

Not clear is, if both the "scavenged prechamber" and the "unscavenged prechamber" case are investigated in Fig. 10.1, where the temporal evolution of the main ignition is shown from high speed flame chemiluminescence measurements (why does the author never write which technique he used for which results ?). The description should include this.

The results shown in Figs. 10.2 and 10.3 are nice, showing interesting details. Chapter 10.3 and 10.4 comes to the mentioned topics of unscavenged vs. scavenged prechamber.

Question here to the author: Is your statement correct that the same total amount of fuel but more of it inside the prechamber and less in the main chamber increases the measured cumulative heat release significantly (32% you state end of chapter 10.4).

In Chapter 10.5 the ignition limits have been investigated for the scavenged prechamber ignition. This comparison between conventional spark ignition limit (lambda 1.75) and prechamber ignition limits (lambda 1.9 to 2.2) is probably the most central result of this thesis. The Figures 10.10 and 10.11 are probably very useful - also for modelling studies (which we are currently doing on this issue). This part should be published internationally.

Chapter 11 compares direct spark ignition with prechamber ignition (= turbulent jet ignition). It confirms strongly what is expected on turbulent jet ignition. The first sentence of 11 rises the expectation that the advantages and disadvantages of the turbulent jet ignition are investigated or described. The chapter then describes only the advantages. I propose to change the first sentence, as the description of the disadvantages (more expensive ignition system with scavenging) are probably beyond the scope of this thesis.

In Chapter 12 then a prechamber ignition system (without scavenging) is built into a real single-cylinder research engine. Pressure and heat release traces are determined and analyzed for leaned mixtures up to lambda = 1.38. For leaned mixtures the cyclic variation of the maximum cylinder pressure is found (is expected). Emissions of NOx are reduced for leaner mixture while HC emission increase (both is expected).

According to the main topic of the thesis (comparison of conventional spark ignition with prechamber ignition of CNG engines) similar measurements with conventional ignition

would appear to be required. The prechamber ignition measurements should at least be compared more with them.

The conclusion chapter 13 currently lists several single observations, especially in chapter 13.2. This gives the impression of just a listing. This are much too much details for a conclusion. Partly they are seem to be unsorted. It gives the impression that they are listed unreflected. Only those points which have been found to be of general value should be discussed in the final chapter (the detail observation have their place in the experimental results chapter). The generalization of the results starts on the last page of chapter 13.2. This is more what is expected. To the content of them I have marked several questions. Generally, here it should be discussed or mentioned whether this or that general result is expected or not, whether it is fitting to the general knowledge or gives a new contribution to the general knowledge. I think it would be a good idea, if one discusses the important excerpts of the measurement results in terms of the thesis points formulated in chapter 2. The second last sentence of 13.2 sounds as if all the research of this thesis did not give answers, as the topic of ignition is too complicated. I have proposed there an alternative formulation as proposal, in the case it hits the intention of the thesis.

Rating of the thesis

- The topic of the thesis is of interest as natural gas engines will probably be a useful solution to reduce the CO2 emission with much easier effort than for instance with electrically driven cars.
- Mr. Bueschke has made interesting experimental studies - especially on a rapid compression machine with optical access. He used very state of the art measurement setup - high speed imaging techniques and others. He investigated prechamber ignition of gas engines which is possibly important for lean engine operation with reduced NOx emissions and increased efficiency.
- The measurements by itself seem to be well done - especially in Chapter 10 they could be published internationally.
- However, the written thesis has many drawbacks in the current version.
- One is the used English language which needs several corrections. Also many words are not separated.
- The written thesis could win significantly if especially at the beginning of the different result chapters the backward reference to the experimental setup and also to the research question to be described in that sector would be given.
- One other drawback is that the thesis gives the impression that Mr. Bueschke is more the detailed experimentalist. Generalizations are not yet the focus of his thesis. It is in many parts standing more on the level of description. The last chapter must be rewarded in this respect.
- To my understanding the main results of this research work are not yet published internationally. I believe that some part of it is worth to do so.

Assuming that the more formal aspects will be corrected in the final version of the thesis (English language as well as internal reference to the experimental setup and to the relevant question as well as the more focused last result chapter), I grade the thesis

with "good".

From the content and the used methods the thesis of Mr. Bueschke would allow a better rating, but regarding the lower ability for concise generalizations and the many formal issues I find this grading adequate.

Hannover, den 10.10.2017

Prof. Dr. Friedrich Dinkelacker

Appendix:

Many items have to be corrected, shortened or rewritten, or rearranged until a clear and logically thesis is visible.

English language is not satisfactory.

- Articles (the / a / ....) are in some chapters used wrongly.
- The word "research" is often used instead of "experiments" or "studies" or "measurements" or "investigations" or ...
- Common error is like ".... led to the defining of the internal processes..." (should be "... to the definition of ....").
- Tempus is quite often like "..... has been noted that ..." (while an image is described, so the reader ".... can see that ...")
- Do not write "aren't" - as this is a shortened version. One will not find this in serious text books or articles.
- Fuel "dose" is not common.

I have made some corrections in about half of the thesis, but everywhere an expert in English is needed. Currently this affects the understandability strongly.

The result chapters (7 to 12) are standing alone.

- First sentences of the chapters should introduce what will be done here, and why it is done, and on which experimental setup. Currently this is collected somewhere in chapter 6 - and in Fig. 2.1 (which by itself is good) - but a reader cannot remember that from chapter 6 or chapter 2.

Exchange of chapter 8 and 9 would seem from this point of view more logical. Or a motivation in the text to the chosen order is needed.

Aim of Chapter 6.6 is not yet clear to me.

In chapter 2 some defined "thesis sentence" or "questions" (or "hypothesis") are formulated. That is a bit uncommon but good way. However these points should be used later firstly in the experimental and results sections to motivate why this or that experimental steps are done, and finally these points should be used in the final results discussion and summary. Then the thesis has the chance to become fully rounded.