Base test report

of the

Micro diesel prototypes

This base test description has been written in chronological order of events.

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PRACTICA
FOUNDATION

Contents

Introduction

This report is description of a base test in which 3 prototypes of a 18cc 2-stroke self-igniting stationary engine are compared to the Lohmann auxiliary engine it originates from. This auxiliary engine was produced in the 1950's.

First a test setup has been made on which the 3 engines could be tested. After that the engines were one by one installed on it and different tests have been conducted. Changes to the adjustable parts of the engines have been done during the testing in order to optimize the results.

The results of the test are combined in the Conclusion and the points for next stage optimization have been combined in the next stage improvements

1. Test set up

Test objective
The objective of this base test is measuring the difference of power output and specific fuel consumption between the data of the original Lohmann auxiliary engine and the 3 prototypes now available at Practica

Test items
For this test 3 engines have been made with small differences:

- Prototype 1 'Original engine'
  This engine has been constructed from original parts of the German "Lohmann" engine used in the 1950's as an auxiliary engine on a bicycle. A 4:1 gearing has been added to the engine making the output shaft turn around 1500 rpm and a 16:1 gearing for hand starting
- Prototype 2 'Dutch engine'
  This engine has been made in the Netherlands, by translating the 2D design in 3D using Solidworks. This 3D design has been used to make a prototype.
- Prototype 3 'Chinese engine'
  This engine has been made by the Hang Zhou technical University in china, using the 2D drawings based on the original engine.

Test equipment

- Torq sensor/rpm sensor
- Hysteresis brake
- temperature sensor
- small diameter pipet, for measuring fuel consumption
- Gedore digital calliper accuracy ±0,01mm

Fuel
The original Lohmann engine on which the Micro diesel is based, is supposed to run on multiple fuels. But the most commonly used is a mixture of Kerosene and 2 stroke oil in the proportion 25:1 or 20:1.
During the test it was chosen to use 20:1, which means a bit more oil for lubrication of the prototype engines, to decrease the risk of seizure during the testing period.

Setup test with prototype 1; 'Original Engine'
First a start has been made with the 1st prototype, it first has been fitted to the test bench. After trial runs it was found that a stable reading from the torque sensor was not possible. During the trial runs an unbalance in the coupling connected to the engine was visible. The coupling has been rebalanced and fitted to the engine, this made little to no difference to the torque sensor readings.

The Hysteresis brake also had been calibrated accurately, so it was chosen to use the brake current readings for determining the torque, together with the RPM sensor the power output in Watt could be calculated.

Fuel consumption
After this, the first runs of the engine could begin. As a crude test first the fuel consumption was checked. The goal of the test was to replicate the consumption of the original Lohmann engine[1].

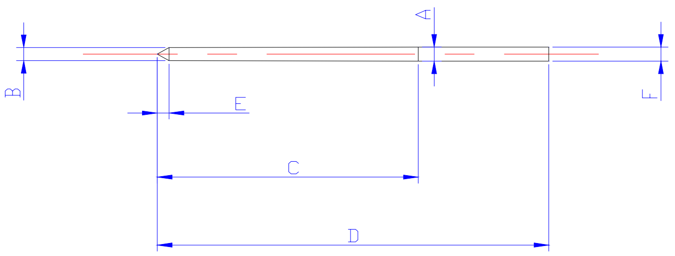
The first tests on fuel consumption gave a result of around 1 litre per hour, compared to the 0,3 litre of the Lohmann, it was insufficient to start testing yet.
First, time had to be spent on finding the differences between the Lohmann auxiliary engine and the original prototype engine to decrease this big difference in fuel consumption

The most likely part to start comparing was the “Mixer”. The mixer takes care of the amount of fuel to be sucked into the crankcase, it does so by opening and closing a needle into a small pipe directly attached to the fuel hose, this combined with an air valve which increases/decreases the size of the air intake.

Measuring the Mixer parts
The mixer needed to be checked, to see if it was the same as the original mixer. At the moment off testing the original needle and valve were not available at the Practica office.
Comparison of part has been done based on the drawings of the Lohmann parts.

- -1 Needle
- -2 Needle valve
- -3 Air valve

Needle
The needles were all measured, it was found that the slope of the needles differed and also the roundness. For example the Chinese needle looked to be hand filed, it was not round and had a rough surface. The dimensions of the Dutch needle are close to the original needle. (see table)

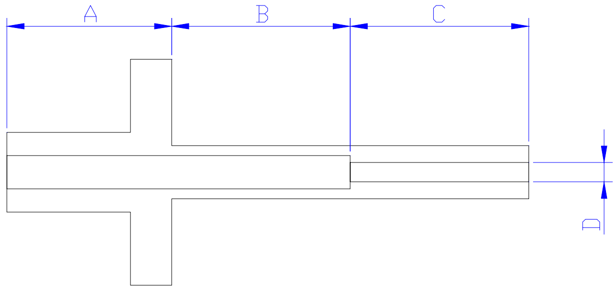


	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)
Lohmann needle	1,4	1,3	22	33	1	1,4
Dutch needle	1,38	1,29	22	33,14	1	1,38
Chinese needle	1,38	1	16	32,64	1	1,38

[1] data taken from *Rozendaal,J. (1950); Pon-Lohmann, Rijwiel met Hulpmotor* and *Schroder, W. (1951); Lohmann-Fahrrad-Motor*

Looking at the measurements above it was decided to use the Dutch needle; not only the dimensions were closest to the original needle, also the slope was machined linearly.

Needle valve measurements

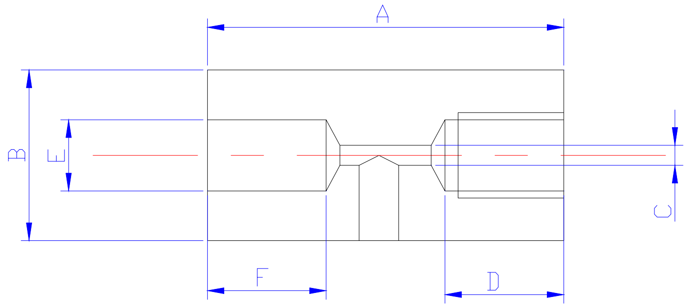


	A (mm)	B (mm)	C (mm)	D (mm)
Lohman needle valve	12	13	13	1,5
Dutch needle valve	21,4	9,27	16,93	1,52
Chinese needle valve	12,12	12,02	10,12	1,41

Picture showing the 3 needle valves from the different prototypes. From the left to the right:
-Prototype 2; 'Dutch engine'
-Prototype 3; 'Chinese engine'
-Prototype 1; 'original engine'

The Dutch needle valve came closest to the measurements of the Lohmann engine, the sizes B and C were machined to replicate the original.

Air valve measurements



	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)
Prototype drawings	27	12	1,4	8	5	9
Dutch air valve	27,21	11,98	1,39	8,11	6,05	8,51
Chinese air valve	26,96	11,95	>1,4	11,15	5,02	7,89

Picture on the right shows both the 2 prototype valves on the left and the original valve on the right.

In the picture above first the two available valves for the test (Chinese and Dutch) are shown. The 3rd is the original air valve that was not present during testing.

The Dutch air valve had measurements closest to the original and has therefore been selected for use in the test.

Finding the right setting
After the best mixer was put together with the most accurate parts a couple of tests were done to find the best setting for the needle compared to the opening of the air valve.

It was found that the engine runs at pretty much any setting. The difference can be found in fuel consumption and power output, for which the setting was optimised

2. Base test prototype 1; 'Original engine'

During the start of the test the original mixer setup was available again. The appearance of the Lohmann air valve was different. The airvalve was longer, but also closed the circular air hole with a circular valve. The Prototypes all had a straight 90 degrees valve, meaning that the opening and closing of the air hole by the regulator is less linear, giving a more different reaction when regulating.

In order to get comparable measurements, the mixer was again changed to do the measurements with the original needle, valve and settings. The original settings of the carburettor where found at an internet site: http://www.lohmann-motoren-werke.de/

After some time it was found that the engine performance started deteriorating up to the point that it had difficulty running. In order to find out what was happening, the engine was disassembled and it was found to be needing an overhaul.

1st prototype overhaul
The engine was taken apart to investigate the parts to find probable causes for the decrease in engine performance.
Observations:

1. Upper piston ring is plated (unlike the other 2) with a chrome layer. This upper ring seems to have little wear. But since it broke during removal from the piston it could not be re-used.
2. Middle piston ring was stuck on the piston at the gap, it had a lot of wear locally around the gap of the ring.
3. The 3rd piston ring was worn equally over the circumference
4. Piston itself showed a black colouration on the left side (when outgoing axle is on the right) this area also contains the gap of the middle piston ring.
5. The cylinder contained two deep scratches, which run from underneath the inlet hole and protrude above the exhaust hole. (These scratches were present before testing, caused by the gudgeon pin).
6. The lowest (3rd) piston ring chamber in the piston was not completely flat; there was a small elevation in the chamber above the gudgeon pin.

The thickness of the piston rings and the ring gap was measured for wear there

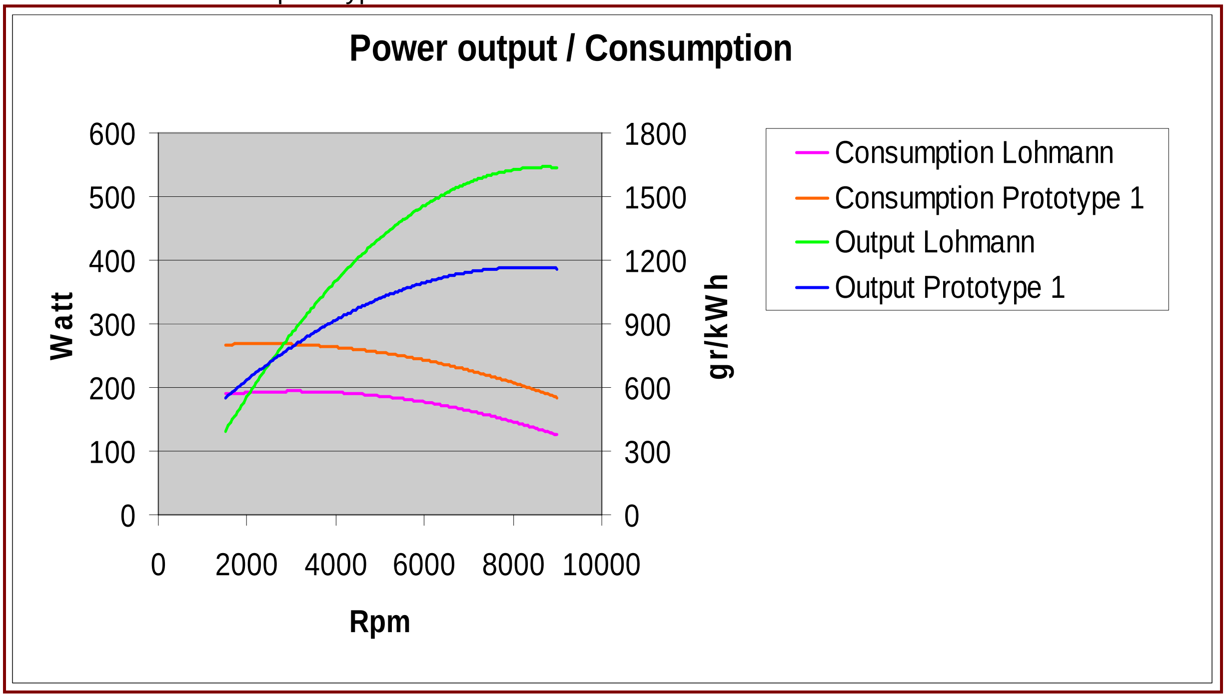
	1 (mm)	2 (mm)	3 (mm)
Used piston ring thickness	1,35-1,39	1,01-1,31	1,16-1,26
New piston ring thickness	1,37-1,47	1,20-1,30	1,19-1,30
Used piston ring gap	*Broken	0,67	0,54
New piston ring gap	0,27	0,39	0,38
**Theoretical gap	0,12-0,16	0,12-0,16	0,12-0,16

* *During disassembly of the top piston ring from the piston it broke, therefore it was not possible to measure the gap in the cylinder barrel.*
** *The theory states that a piston ring gap should be between 0,3-0,4% of the diameter of the cylinder barrel it is running in.*

Possible/probable causes for quick wear
When the engine ran there was a permanent leak past the piston rings through the 2 scratches that in a previous stage have been created by a loose gudgeon pin. This leakage is situated close to the gap of the middle piston ring, carbon started to build up behind the piston ring in this area, filling up the empty space and pushing the ring onto the cylinder, causing the local extensive wear around the gap. The already existing permanent leak caused by the scratches in the cylinder added up to the extensively worn middle piston ring together made it impossible to achieve the right pressure for self-ignition.

After the overhaul, the engine was tested. At different RPM settings, the maximum torque was measured wih the air valve fully open, increasing the load till the RPM was reduced to the correct value (This was done by raising the brake power of the Hysteresis brake).

In the figure below the specific consumption data and output data[2] of the original Lohmann engine is set against the data of the 1st prototype.



[2] data taken from *Rozendaal,J. (1950); Pon-Lohmann, Rijwiel met Hulpmotor* and *Schroder, W. (1951); Lohmann-Fahrrad-Motor*

As can be seen in the above picture, both the specific consumption and output of the original Lohmann engine are better.
The reason why the original Lohmann data shows a better result , might be due to a couple of things:
-state of prototype 1 (leak path between cylinder and piston because of scratches)
-composition of the kerosene used for testing
-reliability of the original data sheet

Observations during test
During the measurements it was found that after the engine had been running for a while, it was not possible any more to achieve the maximum torque and Rpm of the first measurements. After a period of cooling, with the engine off and the cooling water running, the engine could approach the 1st measurements again. Directly after the second measurement was done. Between the 2nd and 3rd measurement a cooling period has been introduced again.

The point above might indicate a heat exchange problem, as the engine runs better when it has been cooled for some time. This will be looked at in a later stage.

3. Base test Prototype 2; 'Dutch engine'

The Dutch engine was build with no original parts inside. Except for the crankshaft en piston setup everything was made in the Netherlands. During the trial runs there were some problems indicating a compression problem, therefore the piston setup was checked first.

Chinese setup
In China a series of 250 piston sets have been produced for the micro diesel engine development, one set exists of:
- -1 piston
- -3 piston rings
- -1 gudgeon pin
- -2 circlips

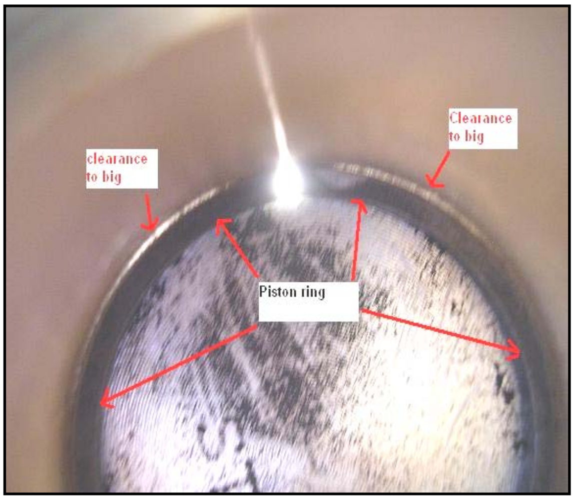
Chinese piston setup

In order to get an idea on how good the total set is it had been installed on the dutch prototype. After some time of starting, it was found that when giving it full compression, it gave some ignition but not regularly, not enough to make it run.

In the test with the 1st prototype, it was found that after revision, the engine could be started from cold with new original rings. This means the 2nd prototype has less compression, as the mixer was exactly the same as on the 1st prototype. The reason for this lower compression was checked.

Most likely the problem off compression loss would be in between the cylinder and piston rings. Therefore a bushing was made with a similar size as the cylinder (new cylinder should be 28.0 +0.01/-0,00), size of the bushing made is 28.04
Inside this bushing the Chinese rings were placed to see if a clearance would be visible in bright light.

The left picture (below) gives an example of a Chinese piston ring in a cylinder barrel-size bushing. On the right an original ring in the same bushing.

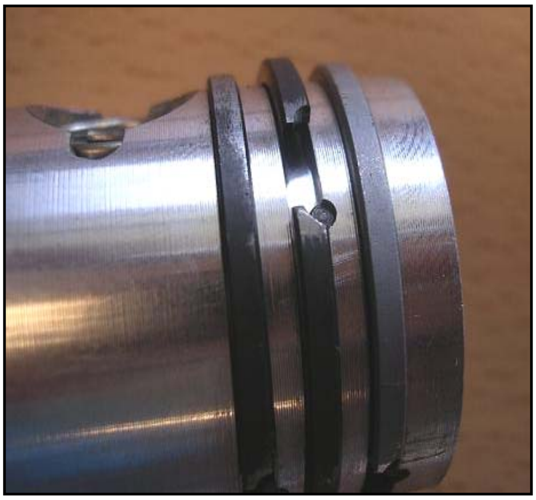


Chinese made piston ring


Original piston ring

The difference can easily be seen: the Chinese ring not only has a ring gap where light is visible, but also along the circumference there is a clearance where light can pass. This means that the Chinese rings compared to the original rings would have more leakage past the rings with a similar gap size.

After the light check, the Chinese piston and rings were removed from the Dutch engine to be inspected. The rings had a thin protective coating that was partly worn on the places where it touched the circumference of the cylinder barrel. The parts that did not touch the cylinder barrel circumference still had the protective layer. As can be seen on the left picture below (looking at the middle ring), the ring ends forming the ring-gap have lost its protective layer and are shiny. The parts beside the ends are still completely coated black.
The right picture is showing the opposite side of the middle ring, which is much more evenly worn.


At the ring gap its worn locally

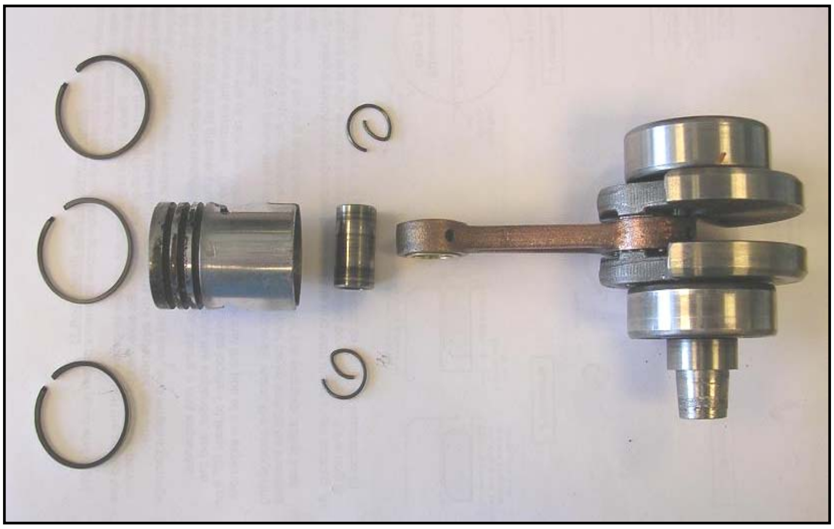

At the opposite side its evenly worn

Conclusion
The Chinese piston rings do not make a good enough seal. For a self igniting engine the seal it makes is not sufficient to reach a pressure at which the fuel mixture will self-ignite.

In the next stage off testing more time will be spend on determining the right seal for the micro diesel, looking at the piston, cylinder and rings. For this moment usage of the original rings (as sold for the Lohmann auxiliary engine in the 1950s) on the Chinese piston is good for getting the base testing done. The next phase will be concentrating on performance improvements.

Overhaul
After running the Dutch prototype engine with original new piston rings for about 4 hours the engine stalled and seized up.

No attempts have been made to force the engine to turn, but disassembly was started as the next step to try to isolate the original cause.



Damaged crankshaft / piston set up

Observations:

1. After about 4 hours of running there is an amount of black deposit on the piston. This deposit is mostly above the top piston ring and at the position of each ring gap, especially a lot of deposit was concentrated around the middle ring gap.
2. The top and middle ring were not freely positioned in its chamber any more, they could be moved, but not without some drag.
3. After removal of the piston rings it was found that the middle ring had not been equally supported in the piston chamber on the bottom side. A clean patch (no deposit) was visible on the ring with black deposit on both sides. On the piston there was a similar spot at the corresponding position.

Bottom of middle piston ring, with a circle around the clean patch.

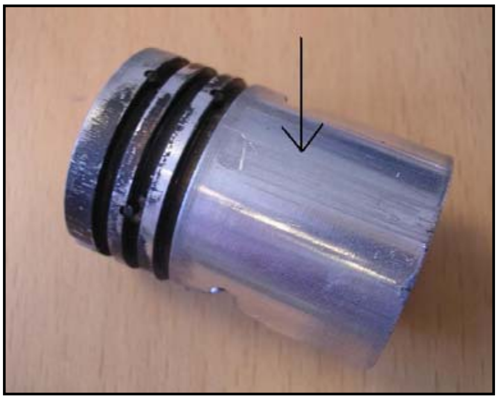
4. After cleaning the deposit from the top of the piston damage to the piston was visible

Top of new piston

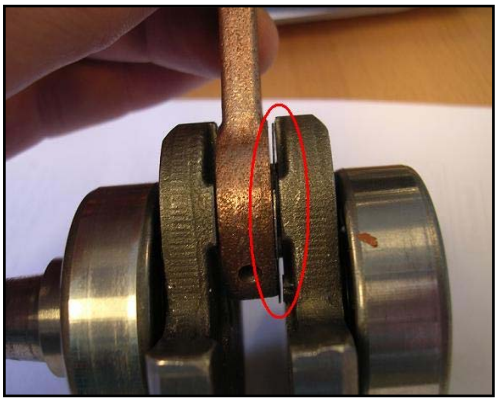
Top of damaged piston

5. The piston showed a broad groove, material has been removed.

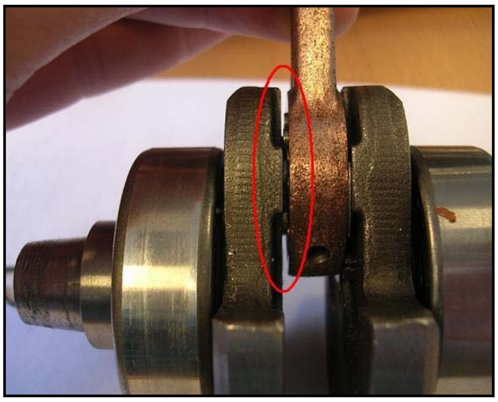
Piston showing a broad groove over the full length



The crankshaft-connecting rod bearing was missing 1 retainer plate/washer.



Right side plate still there

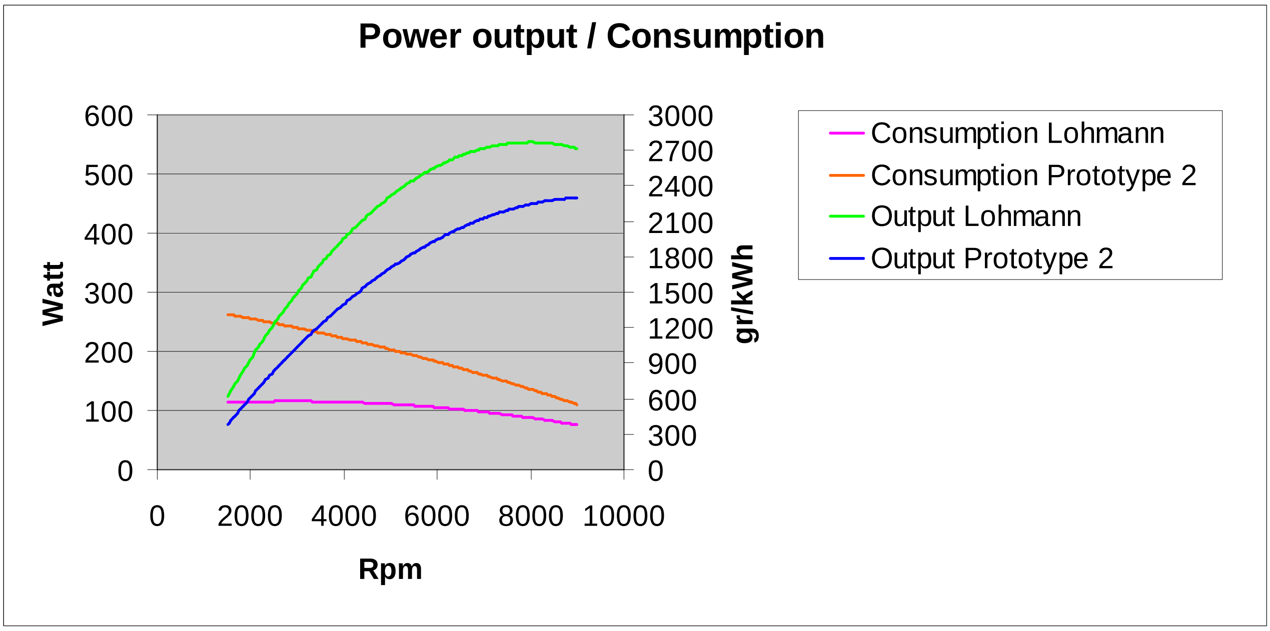


Left side plate missing

6. The inside of the crankcase was scratched and littered with small pieces of mangled metal. These pieces were also found in the combustion chamber and in between.

Possible and probable causes:
The retaining plate is held in place by a small fixing pin. This pin prevents the plate from rotating. Its possible that this pin was not long enough to hold the retaining plate, so the retaining plate past the pin which makes the clearance between the plate and the bearing smaller. Possibly this clearance was too small so the retainer plate started bending. The bend part could have touched the side of the crankshaft (which is not flat) end started to tear the plate apart.

Test results Prototype 2
After examination a new crankshaft and piston were fitted and the engine was tested the same way as prototype 1. The testresults are shown below.



As can be seen in the graph above the power output and consumption of the 2nd prototype are not similar to the original Lohmann Engine. The power output is lower and the specific consumption higher, so also the 2nd prototype needs considerable optimisation before it has similar power output and consumption as the original Lohmann.

Emissions
The emissions of the 2nd prototype is visually not any better than the 1st prototype. It gives a lot of blue and grey smoke when it has to deliver power. When it is running without a load it is considerably less. Anyhow visually the emission is not satisfactory, it looks to be very dirty and needs to improve considerably.

Fuel
From the information on the Lohmann auxiliary engine it was found that multiple types of fuel could be used in the engine. More fuel types for running the micro diesel on, can be a big plus, as then people will be able to choose for the best fuel option in their region.

In order to verify the possibility of running the micro diesel on various types of fuels, a crude test has been done with a couple of random mixtures.
The mixtures used were:
1. 60% turpentine / 25% petroleum / 15% 2 stroke oil
2. 60% petrol (with 2 stroke oil added 1:25)/ 40% petroleum (with 2 stroke oil 1:20)
3. 100% petrol (with 2 stroke oil added 1:25)

It was found that the engine ran on all the mixed fuels. No measurements have been done during this test, as this test was a mere check of the old information on the Lohmann auxiliary engine. The tests have been done with a warm engine so it doesn't say much about the ability to perform a cold start on each mixture. Probably each mixture will have it own maximum output, specific consumption and emission.

3rd Prototype
Both the 1st and 2nd prototype have been tested and both show a considerable lower output and higher

specific consumption. As these two engines have been made most accurately compared to the Chinese version, there is no hope of getting a better result from the Chinese engine or 3rd prototype. Therefore is was chosen not to test the 3rd prototype, but to proceed with the optimisation of the 2nd prototype as a next step

Next step: optimization
The 2nd prototype was chosen to use for optimisation as it is the one produced in the Netherlands, and most easily altered to fit optimization goals. Also it is already using a Chinese piston and crankshaft, and has no original Lohmann parts inside it.

Conclusion

During the test it was found that at this moment the output and specific fuel consumption from the prototypes are not the same as the original data on the Lohmann auxiliary engine states. The Lohmann data says to have a better power output and better specific fuel consumption.
This difference can be explained due to a couple of points:

Difference between engines
The original crankcase had groves at the circumference. The actual reason for this is still not known. During prototype stage it was chosen not o include it in the design as the use was not clear. A possible reason for these grooves or ribs is that they work as an atomizer, atomizing the fuel, which could have a profitable effect on the running of the engine.
The Lohmann engine was not a stationary engine like the micro diesel, and did not have a regulator. The Lohmann engine used the variable port timing in the moving cylinder for its benefit, if a stationary engine can use these same benefits is unsure.

Sensitivity to wear
During testing of the 1st prototype a problem occurred with the original engine having not enough compression to self ignite. The origins of the problem were most probably two big scratches in the cylinder barrel (were already there) which made it possible for carbon to easily build up behind the piston rings. This carbon supposedly pushed the rings outwards, making them wear more rapidly, lowering the compression Sensitivity to wear can be a major problem with small self-igniting engines, causing lower compression and thus starting problems. As feedback from Lohmann users also indicate wear problems, wear of piston rings piston and cylinder need to be a focus point during further optimisation/testing

Emissions
The information on the original Lohmann engine mentions that the first Lohmann auxiliary engines gave a lot of smoke when running; visually they were not very clean. Then another piston ring was placed and the engine became visually cleaner.
During testing it was found that there was a constant blue smoke coming from the exhaust pipe. For present standards the engine is visibly not clean, even though 3 piston rings have been used. Further testing and optimization of the engine will include work on reduction of visible emissions. No quantitative emissions testing will be done until visible emissions have been brought down to visual emission levels of comparable 2-stroke petrol engines.

Composition of the Fuel.
The main fuel mixture prescribed for the Lohmann engine was a mixture of kerosene and oil. Since the 1950's there is considerable doubt the composition of kerosene has changed in time. In one of the articles it was mentioned that the composition has changed in order to make it less toxic and safer for home use. If this was a worldwide change or just in one country is not known. The change in composition may very well have an effect on the way the micro diesel runs.
On the other hand, the articles by Rozendaal and Schroder mention other Fuels like petrol have a much completer ignition in the Lohmann engine. The actual fuel used during the 1950 tests is unknown as the authors have not mentioned it.

Data reliability
The data found was spread by the importer of the Lohmann engine (PON) and this data came from the factory producing the Lohmann engine. So far known, there has been no data check by an unbiased party.

Next stage improvements

The performance of the engine is not yet the same as the original Lohmann engine states to be. The aim of the next stage is to get closer to the values of the Lohmann engine, and emission wise to get an evident visual improvement.

Compression
The compression on both the tested engines can be improved, this may very possible extend the lifetime of the engine, as it will take a longer time to reach the critical compression where the engine will no longer self-ignite. Points of interest are:

- *Size of the cylinder compared to the size of the Chinese pistons*
  At this moment the Chinese piston used in the Dutch engine has a smaller diameter than indicated in the drawing. How this effects the engine is a question that needs answering. More importantly the correct clearance between the cylinder and piston needs to be determined and tested in the next phase;
- *Minimal piston ring gap size*
  The general rule for piston ring gap size is 0.3-0.4% of the diameter of the cylinder barrel. High performance engines tend to have a bigger gap size, because of higher operating temperatures, what will cause the rings to expand more. At this moment the gap size of the standard ring does not correspond with the theory as it is considerably bigger. Finding out the reason for this and finding the minimal gap by testing will be a good step into improving the compression;
- *Seal of the piston ring onto the cylinder barrel.*
  As has been found out during the test of the Chinese piston set up, a better way of producing rings needs to be found. The ring needs to seal the cylinder barrel at the complete circumference. An alternative ring design giving a better seal/compression can be an important step for optimisation.

Atomization of the fuel
As came forward in the conclusion, the atomization of the fuel might be a point of improvement for the engine, giving it a better and cleaner ignition. As at this stage it is a mere theory, it needs to be verified by testing.
Possibilities for checking this theory would be adding the original grooves to the crankcase, looking at the size of the clearance between the crankcase and the crankshaft. Possibly this will influence the particle size. Another possibility would be to experiment with the way the fuel enters the engine, as now the fuel is just dripping into the engine; an atomized entry of the fuel could possibly have a beneficial effect.

Fuel mixing
A range of mixtures available in the target countries for the Micro diesel will need to be tested more extensively. The settings of the mixer/carburettor will have to be fine-tuned to each mixture, as viscosity of the fuel mixes differs. Output tests and consumption tests can be performed on the test bench to find the optically cleanest, most economical and highest powered mixture.

Cooling
At the test of the first prototype as well as the second prototype, the engine has been cooled in between tests, as it was found that the engine could not replicate its maximum performance after running for a longer period at the time. This could indicate that the engine overheats due to insufficient cooling due to a poor heat exchange.
This possible insufficient heat exchange could be caused by the clearance between cylinder barrel and housing. The problem of heat exchange between cylinder and housing used to be a problem which has been solved in modern engines

Stationary running
While testing, it has been found that the prototypes are very sensitive on changes of temperature and load. In practise this means that the engine constantly needs compression changes. When the engine is heated up properly, the changes are less frequently, but still appear. This means that the state the engines are in now, they will need frequent compression adjustments, which are not practical for a stationary engine. Further testing should give more information on this issue.