Mechanical Engineering, 60 credits

MASTERUPPSATS

Engine stability

A study of the events occurring prior to the combustion in a small two-stroke engine

Alexander Mattsson

Master thesis, 15 credits

Halmstad 2017-05-19

PREFACE

This report is written as a final thesis during a one year masters study at Halmstad university. The thesis is conducted in collaboration with Husqvarna AB, the hosting group during the thesis is the engine performance group.

I would like to thank industrial supervisor Rikard Rydberg, for all the time and brain storming sessions, Joakim Arvby head of Husqvarna Global Services, for making this project possible, my mentor Mattias Bokinge for the guidance in all the academic aspects and of course my girlfriend Camilla Gonzalez for all the understanding and patience.

Halmstad, May 2017

Alexander Mattsson

076-817 85 33
mattsson_alexander@hotmail.com

ABSTRACT

This thesis is a study conducted in collaboration with the engine performance group at Husqvarna AB. The study focuses on engine stability of smaller two stroke handheld engines running on E10 (10% ethanol mixture in gasoline). The reason for the study is the new EU proposition that by 2020 all fuel must have 10 % renewable fuel content. To meet this proposition Husqvarna has evaluated E10 and found that the engine stability of smaller two stroke engines are affected in a negative way by the fuel.
The study focuses on events occurring prior to the combustion and mainly the carburetor. The objective for the thesis is to seek what contribution the events occurring prior to the combustion have to the engine stability and find simple and implantable solution to improve the stability with regards to the carburetor.

The study has been conducted in three different work packages, system understanding to build knowledge of how the carburetor operates, fault finding to seek potential attributes that can affect the stability and fault mode analysis to seek why the attributes affect the stability. Furthermore, all the attributes found has been tested and validated on the engine to seek their contribution to the stability.

The conclusion made of the thesis is that with simple and implementable improvements of the carburetor the engine stability could be increased with 40 %. A total of five different attributes were found to affect the stability of the engine. Furthermore, a very detailed explanation of how the carburetor operates and components inside the carburetor has been established during the thesis.

CONTENTS

Figure list

Graph list

Table list

Equation list

Terminology

Fuel	In this thesis fuel is used when talking about fuel in general for this thesis it could be gasoline, ethanol or gasoline ethanol mixture
Gasoline	During this thesis gasoline is 95 octane gasoline
E10	E10 is 95 octane gasoline mixed with 10 % ethanol
CFD	Computational fluid dynamics
CAD	Computer aided design
.step	A CAD file format
Mathematica	Calculation program
RPS	Rounds per second
Lean	When the engine is running on to low fuel compared to air
Rich	When the engine is running on to much fuel compared to air
Dynamo	A machine used to measure power output from engines
HC	Carbon hydrates
NOx	Nitrogen dioxide
Co	Carbon monoxide
Co_2	Carbon dioxide
Maximum power speed	The engine speed where the engine generates maximum power output
Maximum engine speed	The maximum speed that the engine can reach

1 INTRODUCTION

In handheld petrol powered products two stoke engines are very common, mainly for their simplicity and light weight. A disadvantage of a two stoke engine is the emission rate, manufactures of two-stroke engines works very active to lower the emissions produced by the engines. The major downsides of the emission on two-stroke engines are that they use oil in the fuel for lubrication and flush un-combusted fuel through the engine.
This thesis is a study about the engine stability of smaller two-stroke handheld engines, the specific engine of the study is a 40 cc engine running on the biofuel E10 (10% ethanol mixture in the gasoline). During this thesis the engine stability is defined as the variation of the Co and Co^2 levels leaving the exhausts system. The study focuses on events occurring prior the combustion and mainly on the carburetor. The objective of the thesis is to find simple and implementable solutions to a carburetor for increased engine stability.

1. Presentation of the client

The thesis is conducted at Husqvarna AB a company owned by Husqvarna Group, Husqvarna Group is a large company with more than 13000 employees. The company have a wide range of products such as auto movers, riders, electric powered chain saws and brush cutters, their main turnover is from the hand-held petrol powered equipment such as brush cutters, hedge trimmers and chain saws.

There is a proposition in EU that by 2020 all fuel should have at least 10% renewable fuel content (EU, 2017). A suited renewable fuel to fit a two-stroke engine is E10, since ethanol is produced by bio materials it is a more environmental friendly fuel than gasoline.

To meet the new EU proposition Husqvarna has evaluated E10 compared to gasoline. The findings where that smaller two-stroke engines stability seems to be affected in a negative way by the ethanol mixture.

If the engine is unstable the performance of the engine will be affected, mainly due to loss of power. Other important aspects are that the operating temperature of the engine will increase, this will shorten the life span of the engine as well as increasing the emissions of the engine. In the article Experimental investigation of exhaust temperature and delivery ratio effect on emissions and performance of a gasoline-ethanol two-stroke engine (Ghazikhani, Hatami, Safari, & Ganji, 2014) a study of the temperature effect with regards to the emission rate was conducted. The conclusion of the study was that a lower operating temperature of the engine produces less emissions. Thereby if stability is increased the operating temperature is decreased and lowering the emissions produced by the engine.

1.2 Engine stability

The stability of an engine can be measured in different ways, one way is to measure the pressure inside the combustion chamber between the cycles. Another one is to analyze the content of the exhausts to estimate how the air to fuel ratio was during the combustion. Stability during this study is defined as the variation of the Co and Co^2 levels leaving the exhaust system. The Co and Co^2 level will be measured by a portable emission analyzer that measure both Co and Co^2 levels in the mixture that leaves the exhaust system. The measurement of the stability is then the standard deviation of the Co/Co^2 when the engine is running on maximum power speed and the cylinder top temperature has stagnated.

1.3 Aim of the study

Seek a system understanding of how the stability can be affected by events occurring prior to the combustion. The main objective is to study the carburetors contribution to the stability, yet not limited to only the carburetor.
This will be conducted by establish a structured way of investigating the events occurring prior to the combustion and their affection of the stability. With the gained knowledge of the events contribution to the engine stability, present simple implementable product improvements of the carburetor.

1.3.1 Research questions

- What contribution does the events occurring prior to the combustion have to the engine stability?
- Can simple modifications to an already designed carburetor increase the engine stability?

1.3.2 Work structure for the thesis

The thesis can be broken down into three different work packages each, following in sequence, they will eventually produce the suggested product improvement. The three packages are system understanding, fault mode finding and fault mode analysis. A deeper presentation of the different work packages can be found under chapter 2 methods.

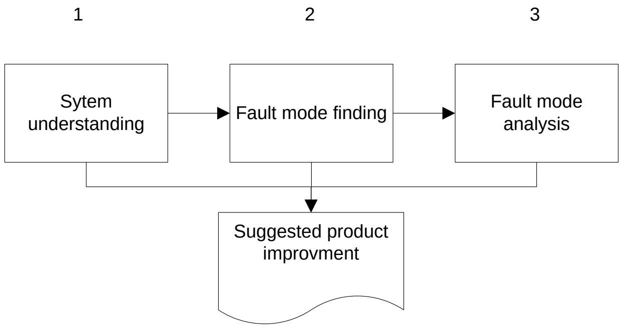


Figure 1 Work flow during the thesis

1.3 Limitations

The project does not focus on any events during the combustion or post the combustion.
The mission system of the thesis is the carburetor, the systems that will be examined is all systems in contact with fuel prior to the combustion. The product improvement that will be delivered is only with regards to the carburetors function.
The examined carburetor is already designed and the manufacturing tools are in place. Thereby a product improvement is a more effective, sustainable and economical than redesign the complete carburetor and manufacture new tools. This leaves the study to only focus on easy implantable product improvements. There will be no complete evaluation of the risk, manufacturability and trade off presented during the thesis, this work will be conducted by Husqvarna AB. Although all the presented improvements must be manufacturable and not harming the carburetors quality or performance.

1.4 Study environment

The thesis is conducted at site at Husqvarna AB product and engine laboratory. The hosting group under the thesis is called engine performance group, they are responsible for the engine performance in aspect of drivability. The group works closely with the complete R&D organization.

During the study a wide range of equipment in the laboratory has been used such as emission analyzers, dynamos, pressure measurement equipment and a wide range of other analyzing equipment's. Furthermore the calculation program Mathematica has been used to make some calculations during the thesis.

2 METHOD

During this chapter methods that can be applied during the three different work packages will be presented and discussed, as well as the content for each work package.

During heading 2.4 chosen methodology the chosen methods for each work packages will be presented

2.1 System understanding

The main objective during this work package of the thesis is to gain knowledge of how the complete engine operates and especially the systems prior to the combustion. The analysis should briefly cover the complete engine function but with focus drawn to events prior the combustion. The reason of including the complete engine is to not miss any important relationships between the sub systems, this was a recommendation from the hosting group. Since the engine is a complex system there is a need to find a structured way of analyzing the system. With the amount of components and functions that is involved in the events occurring prior to the combustion there is a need for the method to be compatible with multi system analysis.

System engineering

An engine is a complex system with a lot of sub system affecting the performance of the engine. These types of problems are often solved with system engineering, a definition of system engineering can be "A logical sequence of activities and decisions that transforms an operational need into a description of system performance parameters and a preferred system configuration". Since system engineering is a multi-disciplined engineering most of the literature is written in a more common manner to give the reader more flexibility with the implementation. The system engineering is most commonly found in computer science but is used in a range of other branches as well. (Wasson, 2016)

Abstraction level system

When investigating a system that involves multiple systems the need to define what system that are of interest and the ones that are not is crucial. This could be executed by working with different levels of abstraction when gaining knowledge about the system. In chapter 8 of the book System engineering analysis, design and development by Charles S. Wasson a method of defining abstraction levels in complex system is presented (Wasson, 2016). The model is based on briefly defining the complete system, then the sub systems of the complete system. After that focus is drawn to the system of interest. In cases where the system of interest involves more than one system a mission system can be defined. When defining the hierarchy of the different system it is easier to see where to put the focus.

When having the complete system defined although in a more indefinite manner the relations to other systems becomes more visual and thereby clearer. By working with an abstraction levels system, the risk of missing relations between system is minimized.

System mapping

The method of system mapping is often found in management and in computer science. The method is based on visually mapping a system, often conducted with influences of basic flow charts. The difference between system mapping and a flow chart is that the system mapping could involve, both logical gates and more complex relationships.
The method is very helpful in abstract system but can be tricky to implement in systems where a lot of different sub systems is used. (Boulanger, 2014)

Reversed engineering

The method of reversed engineering is to disassemble a product into its components and seek the function of each component. After the function has been established the next step is to seek the relations between the components. When conducting a reversed engineering of a product, a deeper understanding of the product is gained. In the book The mechanical design process by (Ullman, 2010), templates for reverse engineering structure is presented. The template is built to, in a structured way communicate the function of a product to a reader. It also generates space for a graphical presentation of the examined system.

Function analysis

The function analysis method is similar to the reversed engineering method, but not as defined as the reversed engineering method. The function analysis focuses more of the function needed of the component than the actual function of the component. The method gives the user a more undefined function of the component compared to a reversed engineering. This type of analysis is often used in product development, where some abstraction often is needed to not harm innovation. (Ullman, 2010)

2.2 Fault finding methods

The main purpose during this work packages of the thesis is to seek what attributes that could affect the stability of the engine. To seek attributes that affect the stability of the engine in a organized way, some type of structured investigation method is needed. Many off the structured investigation methods are collected from the field quality control or TQM (total quality management) (Andersen & Fagerhaug, 2006). The main objective is to build a structure of possible attributes that could affect the stability.
Since there will be a couple of sub systems, the method needs to be compatible with more than one system.
The data for the analysis will mainly be collected by interviewing engineers at Husqvarna AB and by analyzing the function of the system.

Fault tree analysis

Fault tree analysis was developed by the Bells telephone laboratories in 1962, ever since it has been used and improved. Today it assists many different engineering areas such as mechanical, system and electrical. The analysis is based on a tree structure where a cause or fail mode is presented in the top.

Then it follows with undeveloped events that could cause the problem, the undeveloped events should not be the final cause of the problem.

To define the true attribute that can cause the problem a basic event is used.
This is then presented in a tree where the top events is presented in the top of the tree and then branches out to the undeveloped events to be finalized with basic events. This structure is taken from NASA and is presented at their webpage (Bill, 2017).
To further develop a fault tree logical gates can be applied to the tree to indicate the relations between the basic events. This is presented on a deeper level in the book Handbook of performability engineering chapter 48 (Krishna B, 2008).

Cause effect diagram

The cause effect diagram is often used when trying to seek a root cause to the problem. It is based on a main problem and different causes that can lead the main problem. This method gives a good graphical presentation of different causes and their relations to each other. The method is commonly used in process optimizations cases such as SMED for example. (Evan & Lindsay, 2014)

5 Why

5 why is a method to seek the root cause of a fault that has occurred. The method is based on asking why five or more times to seek the underlaying aspects of the problem. The method is widely used in quality management and root cause analysis. The method is suitable if a deeper understanding of a problem is needed. (Andersen & Fagerhaug, 2006)

Interviews

A way to collect data and seek understanding of problems related to the engine stability is to interview engineers on site at Husqvarna AB. Interviews can be conducted in multiple different ways, structured, semi structured and investigative are just a few.
The task of interviewing engineers is to seek a deeper understanding and thereby semi structured is most likely the proper technique. This is due to the fact that the outcome of the interview is hard to estimate, making it difficult to have a complete defined structure of the interview to follow. One crucial aspect of a semi structured interview is to not ask any leading questions, instead trying to have them as open as possible. (Andersen & Fagerhaug, 2006)

2.3 Fault mode analysis

During this work package the objective is to establish a theoretical foundation of each basic event. At first the basic events will be examined theoretically to seek why they can affect the stability. This will be executed with basic fluid calculations or with reasoning on a theoretical basis. To further investigate the contribution, prototypes of the theoretical findings will be built and tested to seek their contribution to the engine stability.
Formulas and fluid mechanics theory will be collected from literature, the measurements of stability of the prototypes will be evaluated by the method presented under heading 2.5 Definition of stability.

Basic flow calculations

Many complex problems can often be simplified to fit into one dimensional calculations and models, this saves both time and effort. When calculating one dimensional problems the resources and programs needed are very simple. The limitations of simpler one dimensional calculations is visualization and the deeper understanding of turbulence. In one dimensional calculations turbulence is often treated as a constant that only symbolizes loss off a turbulent flow. (Young, Munson, Okisihi, & Huebsch, 2007)

CFD

CFD calculations is computer aided calculations of fluid mechanics, it can be both static and dynamically calculated. In many CFD programs .step files can be implemented from a CAD model to calculate flow around or inside the models. CFD models can visualize turbulence in a graphical way and thereby give the user knowledge of how the turbulence evolves in different areas.

When building CFD models the builder of the model needs to have very detailed information of all the parameters that concern the model. This is often gathered by physically measuring the model and the fluid. (Young, Munson, Okisihi, & Huebsch, 2007)

Benchmarking

Benchmarking is a method where other products are evaluated with regards to the examined product. The objective is to seek how competitors which can be both internal and external has chosen to solve a specific problem or function. A major part of the method is to evaluate how the competitors has chosen to build their function, thereby collecting ideas and opportunities during the evaluation. (Ullman, 2010)

2.4 Chosen methodology

2.4.1 System understanding

To seek the system understanding the abstraction levels system presented above will be used. This will generate a good graphical view of how the examined system relates to the complete engine. It will also generate space for a brief introduction to the function of a two-stroke engine. It will minimize the risk for missing crucial relationships between systems.

The core understanding of the system will be examined with the reversed engineering from professor Ullmans book. Since the examined system contains over 20 different components it will be divided into sub systems to give a more structured analysis. Furthermore, a system map of the examined system will be established to visualize the flow of the fuel throughout the system. This will simplify the work conducted during the fault finding work package of the thesis.

2.4.2 Fault finding method

The main objective for the method during fault finding work package is to provide a structured way to document the process. The chosen method for this part of the thesis is fault tree analysis, it gives a more structured way of the different problems compared to cause effect diagram. Another major benefit between cause effect diagram and fault tree analysis, is the fault tree analysis is more compatible with multiple systems in one analysis. The data for the analysis will be collected by interviewing engineers, evaluate the reversed engineering documents the and system map.

2.4.3 Fault mode analysis

The different stability attributes established during the fault finding work package will be theoretically examined with theory gathered from the book A brief introduction to fluid mechanics (Young, Munson, Okisihi, & Huebsch, 2007). If calculation is needed the choice will be one dimensional calculations since it will generate the results needed for the evaluation. To further evaluate and validate the concepts, prototypes of the changes will be built and evaluated on their contribution to the stability, this will be executed with the method presented under heading 2.5 Definition of stability.

To further widen the span of ideas a benchmarking of a competitive carburetor will be performed. The benchmarking will be performed with the reversed engineering presented previously, and the main objective is to compare solutions between the two examined carburetors.

2.5 Definition of stability

To define the Co/Co^2 levels a portable emission analyzer will be used, the producer of the analyzer is Horiba and the specific analyzer used is a MEXA-584L. The analyzer measure both the Co and Co^2 levels in percentage leaving the exhaust system. When dividing the Co with the Co^2 a measurement of the air to fuel ratio during the combustion can be estimated.

The stability is then defined as the variation of the Co/Co^2 when running the engine at maximum power speed. To give a comparable measurement of the stability the standard deviation formula will be used over a time span of 200 s. The measuring will only be started when cylinder top temperature stagnates.

If any stability is to be compared to another this is done on the same engine when the cylinder temperatures has correlated.

Measurement uncertainties

When working the measurements of an engine, a lot of different parameters will affect the outcome of the measurement. To secure as reliable measurements as possible a few actions has been taken into consideration.

- The emission analyzer has been calibrated on the specified intervals supplied from the vendor.
- All measurements that are compared to each other during the thesis is measured on the same engine, minimizing the risk of engine parameters affecting the measurement.
- All measurements have been conducted in a controlled and ventilated room with a temperature of 20 ° C, to prevent aspects of air density and temperature.
- The fuel used have never been stored in temperatures above 30° C, which will lead to no evaporation of the fuel before the measuring.
- The engine has been serviced with intervals of every 3 hours of operating, to secure aspects of piston ring sticking and wear effecting the measurement results.

3 THEORY

During this chapter of the thesis all the theoretical aspects of the study will be presented. It starts with a short summary of the state-of-the-art literature used during the thesis and a brief introduction of ethanol as fuel, then the chapter is divided into the three different work packages presented during the previously chapter.

3.1 Summary of the literature study and state-of-the-art

Experimental investigation of exhaust temperature and delivery ratio effect on emissions and performance of a gasoline-ethanol two-stroke engine.

The study is conducted at the Mashald University in Iran by the scientists Mohsen Ghazikhani, Mohammad Hatami , Behrouz Safari and Davood Domiri Ganji. The objective of the study was to seek how the emission and performance of a two-stroke engine is affected when running on gasoline ethanol mixture compared to regular gasoline.

The conclusion of the study shows that the emissions can be lowered by up to 30 % when evaluating the HC and Co levels. Furthermore, they found that the NOx emissions where decreased with a lower exhaust temperature. They also found that there was a relationship between how much ethanol mixture that was used and the exhaust temperature. The cause of the decreased temperature where found to be a larger evaporation energy in ethanol compared to gasoline.

National Measurment system Good practices guide to impulse lines for diffrential-pressure flow meters

The institute behind the good practices is the national measurement system institute of United Kingdom. The purpose of the organization is to provide UK with an infrastructure of laboratories that deliver world-class measurement science and technology and to provide traceable and increasingly accurate standards of measurement.
The practices is aimed to assist during measurements with pressure and flows within pipes with pulsating flow. This is the same type of measurements that must be conducted to investigate fuel and impulse pressure of a carburetor. The practices have multiple references to different research projects within the area of fluid mechanics.

3.2 Biofuel E10

Ethanol is a fuel that is produced out of bio generated sources such as crops, wood, or food waste. Ethanol is often divided into generation one and two where generation one is based on crops and generation two is based on waste products. In a sustainability perspective generation one affects the consumption of crops and thereby lowering the amount of nutriment available on earth. Generation two, which is produced out of bio waste such as wood or food waste will not harm the amount of nutriment available in the world, thereby a more sustainable choice. Production of ethanol starts with generating glucose which later on is fermented into a mash. The mash is then distilled to produce pure ethanol that can be used as a supplement to gasoline.
Since ethanol is produced out of bio materials the Co_2 produced when combusting the ethanol has already been consumed during the photosynthesis of the source to the glucose.
(Biofuels association of Australia, 2017)

There is not only the Co that is in the interest when evaluating the environmental aspects of ethanol, both the level of HC and the NOx levels are decreased when adding ethanol to gasoline.

Since the ethanol molecule ($CH_3\ CH_2OH$) contains out of less carbon atoms than regular gasoline (C_8H_{18}) does, it will lower the HC content in the emissions. Furthermore, the energy needed to evaporate ethanol compared to gasoline is larger it is more than double the energy for ethanol (Young, Munson, Okisihi, & Huebsch, 2007). This will affect the operating temperature of the engine and thereby decreasing the NOx created during the combustion. Both the decreasing of carbon hydrates and the NOx is presented in the article “Experimental investigation of exhaust temperature and delivery ratio effect on emissions and performance of a gasoline-ethanol two-stroke engine” where the scientists has conducted a study of emissions with regards to ethanol mixture in the fuel of two-stroke engines.
(Ghazikhani, Hatami, Safari, & Ganji, 2014)

3.3 System understanding

3.3.1 Presentation of examined systems and mission system

Below in figure 2 the examined system is presented, the complete engine cycle, based on an abstraction level system analysis. It is divided into 4 different levels of abstraction, starting on level one, the most abstract level.
The system of interest in its relations to the complete engine cycle is presented as well as the mission system for the thesis. Below figure 2 follows a shorter explanations of level one, two and the mission system as well as a short summery of the reversed engineering conducted.
Since the examined carburetor consists of 22 different components it has been broken down into four different sub systems to give a more structured analysis. Each sub system is examined with reversed engineering gathered from professor Ullmans book and are presented in appendix one to four.

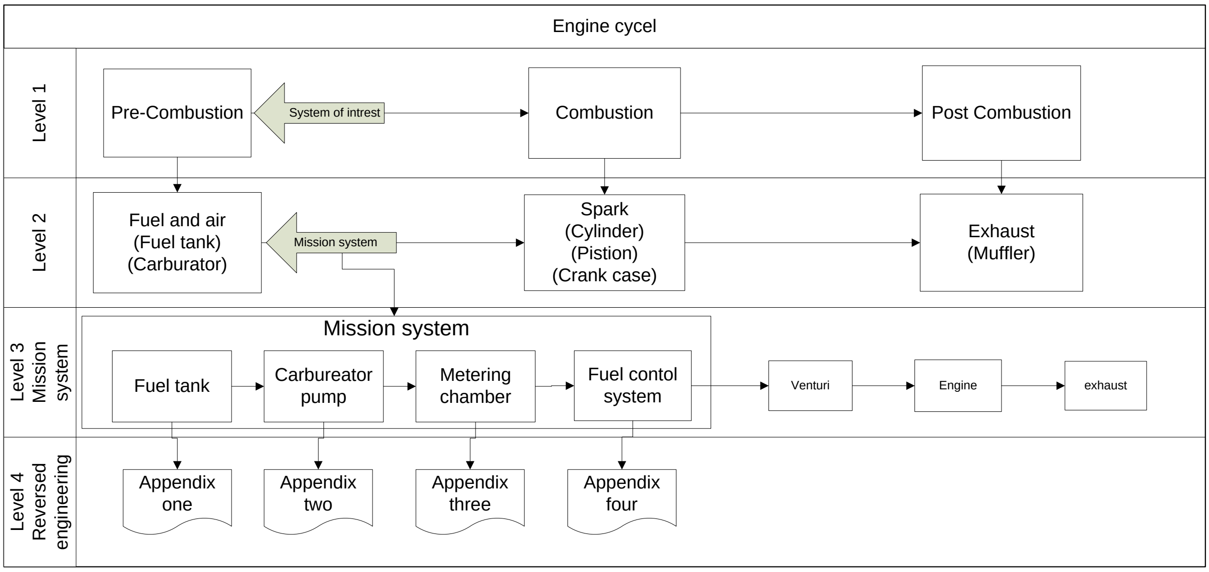


Figure 2 Complete engine cycle based on abstraction level system

Level 1 Basic function of the complete engine

A two-stroke engine completes the full engine cycle in one revolution, in figure 3 a simple sketch of the cycle is presented.
As the inlet port is opened, air and fuel mixture is sucked into to the crank case through the inlet port. Then the mixture is pushed into the transfer port where it is moved to the combustion chamber. Slightly after it reaches the combustion chamber the sparkplug ignites the mixture, creating an explosion that forces the piston down and opening the exhaust port.

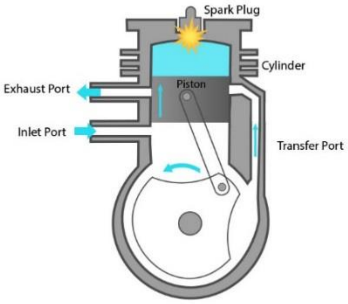


Figure 3 Two-stroke engine sketch

Level 2 Deeper understanding

When fuel is extracted from the carburetor it is mixed with air. The air to fuel ratio needed depends on the engine and the operating speed of the engine. The carburetor has two different circuits a low speed and a high speed. The low speed circuit is designed to feed the engine with fuel when idling and or running on partly open throttle. When the throttle is wide open the main circuit is active providing the engine with a larger amount of fuel.
As the piston is moving upwards an under-pressure inside the crank case occur. This will suck air and fuel mixture from the intake by the inlet port to the crank case. The mixture will then be pushed into the transfer port and then into the combustion chamber. Inside the combustion chamber the mixture will be compressed by the movement of the piston, until the sparkplug ignites the mixture. The explosion will force the piston down, opening the exhaust port for extraction of the exhausts and restarting the engine cycle.

The duration of the cycle when the transfer port and exhaust port are open at the same time will help the engine flushing away exhausts. This gives the engine more power and better drivability but also larger emissions since un-combusted fuel is pushed out in the exhaust system.

The length of the intake and the shape of the transfer port creates a lag between 2 up to 50 engine cycles from when fuel leaves the carburetor until it is inside the combustion chamber.

Level 3 Mission system

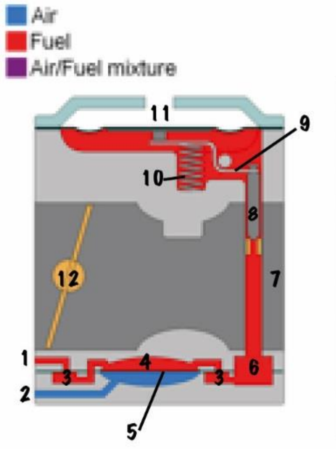
The mission system, the main objective of the thesis, is set to be the fuel tank and the carburetor. This system has 22 different components which makes it hard to present it as one single system. To make a more structured and communicative model of the system it has been divided into four different sub systems.

The flow of the system is presented in figure 2 level 3, the mission system is limited as a starting point when fuel is poured into the tank and ends when the air and fuel mixture leaves the carburetor and goes into the intake.
For deeper understanding of each component inside the system see the summary under next heading or reversed engineering documents provided in appendix one to four.

Level 4 Summary of reversed engineering

Fuel is stored in a sealed volume called the tank casing, with three different connections to the other systems a fuel feed hose, a return hose from the primer and a pressure valve. Fuel is extracted from the tank casing by the carburetor pump or by the user using the primer bulb. The primer bulb is a pump that pumps fuel from the tank casing through the carburetor pump and metering chamber back to the tank casing to fill the carburetor with fuel, when starting the engine. The primer bulb is used by the operator of the engine. The pressure inside the tank is regulated by a pressure valve.

For visual presentation of all the components inside the carburetor see figure 4.
The carburetor pump is based on a membrane pump driven by the impulse (compression and decompression inside the crank case). The fuel is fed to a needle valve that regulates the fuel level inside the metering chamber.
The metering chamber controls the fuel level with a membrane acting on the metering arm that opens the needle valve. As the fuel level is decreased the membrane forces the metering arm down to open the needle valve.



1	Fuel hose connection
2	Impulse connection
3	Back valve
4	Pump chamber
5	Carburator pump membrane
6	Needle chamber
7	Needle seat
8	Needle
9	Metering arm
10	Metering spring
11	Metering chamber membrane
12	Throttle plate

Figure 4 Presentation of carburetor components

For visual presentation of the different work stages of the carburetor please see figure 5
The fuel control system is controlled by a valve opening and closing and thereby controlling the fuel flow. The valve technic is called Autotune, the system optimizes the air to fuel ratio inside the engine. Autotune feeds two different circuits with fuel, the high-speed circuit and the low speed circuit. The low speed circuit consist of a back valve, idle hole and two partly opened throttle holes. The idle hole feeds the engine with fuel when idling the engine and air from hole 2 and 3, the two partly opened throttle holes feeds the engine with fuel on partly open throttle. The main circuit becomes active when the throttle has moved away from hole two and towards the main nozzle, during idle and partly opened throttle a back-valve locks the fuel flow to the main circuit.

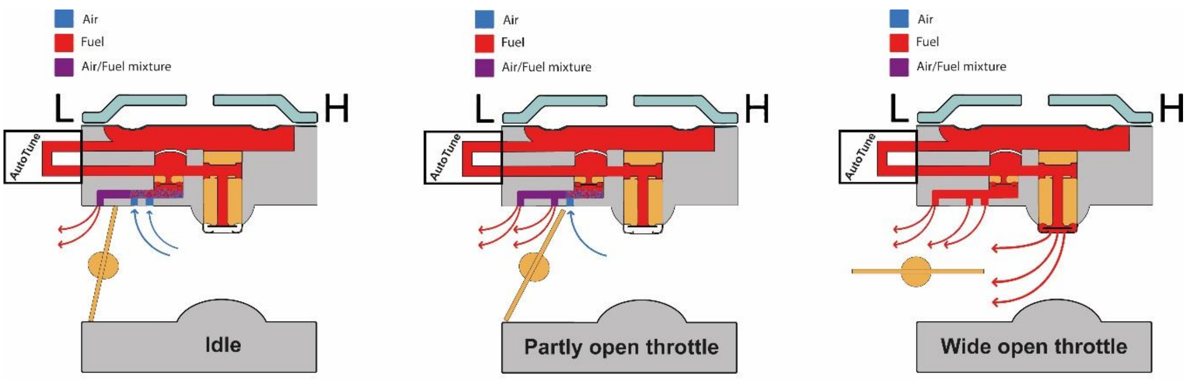


Figure 5 Different operating stages of a carburetor

3.3.2 System map

The system map was established to visualize the fuel flows path from the fuel tank to the venturi of the carburetor. To further visualize how the fuel flows through the system it was marked with red arrows. In figure 6 the system map of the missions system is presented

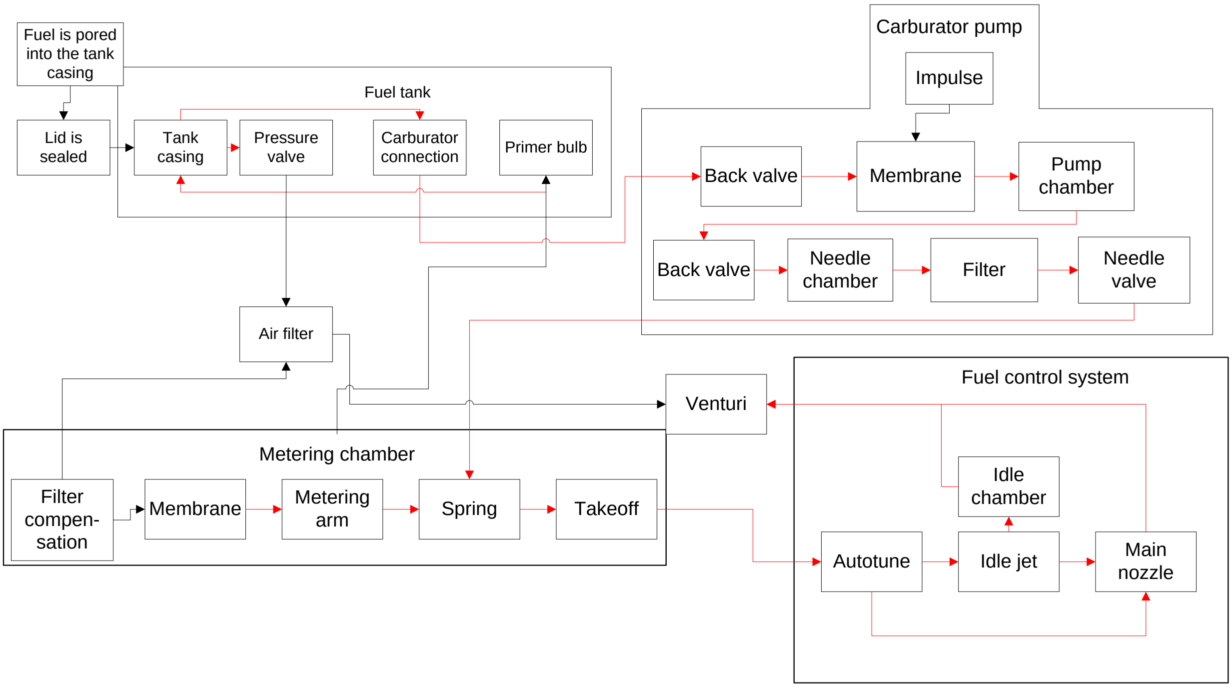


Figure 6 System map of the mission system

3.3 Fault mode finding

The data for the fault tree is collected from three different sources; engineers at Husqvarna AB, system mapping and the reversed engineering. To start the process, a brainstorming session with the hosting group was arranged, with the goal to seek different undeveloped events that could affect the stability of the engine.
With the undeveloped events declared the work of seeking basic events was started. This was conducted by analyzing the reversed engineering documents and the system map of the mission system.

During the analysis of basic events a wide range of different basic events were found, these are presented in appendix six. This list of basic events were then brought to the hosting group for discussion. During the discussion, some events where screened since they had already been excluded previously be the hosting group.

With the basic events established, the fault tree could be constructed, the structure of the fault tree is based on a document collected from NASAs webpage (Bill, 2017). The top event is stated to be unsteady fuel flow to the engine, since this is the main contributor to stability, when focusing on events prior to combustion. The structure of the fault tree is modified to suit the four different sub systems presented during the system analysis.

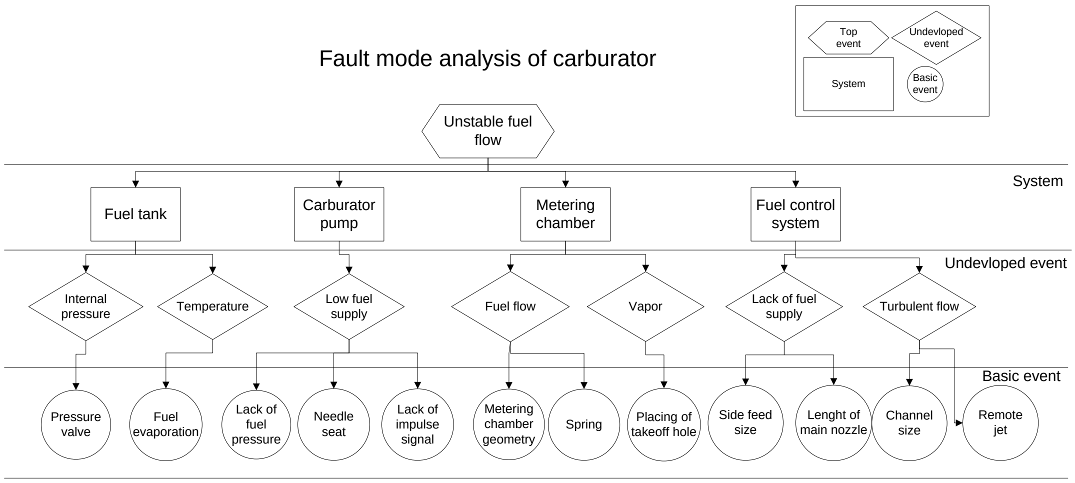


Figure 7 Fault mode analysis

3.4 Fault mode analysis

During this chapter, a theoretical foundation of each basic event presented in figure 5 will be established. Both the function and the possible fault mode will be investigated theoretically. For some basic events calculations will be made to seek optimal function, for others, measurements on the carburetor will be executed. All the presented basic events will be evaluated and validated on the engine, in some cases by simply changing parts, and in other by building complete prototype carburetors. This chapter is divided into the four different sub systems.

3.4.1 Fuel tank theory

Pressure valve

To control the pressure within the tank a pressure valve is fitted on the tank casing. The pressure valve is a two-way valve opening for both underpressure and overpressure. Possible fault modes of the pressure valve can be:

- does not open to underpressure
- opens at a too high or low overpressure.

If the pressure valve does not open for underpressure it will cause the engine to a stop. This is due to that the carburetor pump extract fuel from the tank to the carburetor creating a pressure drop. When the underpressure is larger or equal to the pressure that the pump can generate there will be no fuel flow to the carburetor, hence the engine will stop.

$$-P_{Tank\ casing} \geq P_{carburator\ pump} => No\ flow\ of\ fuel$$

Equation 1Equation of fuel tank underpressure phenomenon

If the pressure valve opens on a higher overpressure it can help the fuel flow of the pump. To analyze this theoretically some assumptions has to be made. One that the fuel flow in the fuel hose and the pump chamber entering hole have the same area. Two that the density stays the same, hence does not change with regards to pressure or temperature. Three that engine is not ran upside down, hence y_1 will always stay positive.

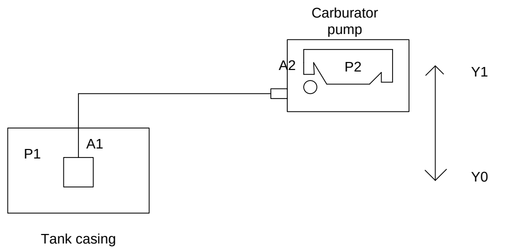


Figure 8 Explaining picture of the model

$$P_1 + \frac{\rho {v_1}^2}{2} + \rho g y_1 = p_2 + \frac{\rho {v_2}^2}{2} + P g y_2$$

Equation 2 Bernoulli's equation

If the area of the fuel hose and the pump chamber inlet is the same and the fuel flow is the same. The velocity will also have to be equal to each other.

$Fuel\ flow = A * P$

$$A_{fuel\ hose} * v_1 = A_{pumpchamber\ inlet} * v_2 \gg v_1 = v_2$$

Since y_0 is the starting point it is equal to zero and since y_1 is stated to always be positive during the examination it can be seen as a positive constant.

With these assumptions made we can now see that if P_1 is increased so is the fuel flow.

$$P_1 + \cancel{\frac{\rho {v_1}^2}{2}} + \overset{0}{\cancel{\rho g y_1}} = p_2 + \cancel{\frac{\rho {v_2}^2}{2}} + P g y_2$$

P	Pressure
ρ	Density
v	Velocity
g	Gravity
y	Elevation

Table 1 Units of Bernoulli's equation

Fuel evaporation

As fuel is heated it transforms from liquid state to gas state, this happens gradually during heating of the liquid. This phenomenon is often presented in distillation curves, where the fuel is gradually heated and the mass is measured. In figure 9 below the effect of adding ethanol to gasoline is presented.

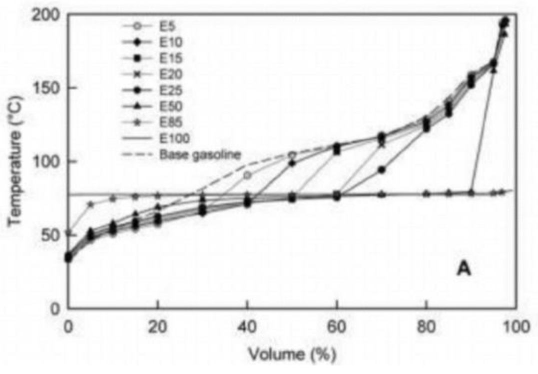


Figure 9 Distillation curve of ethanol gasoline mixture (JiaoQi, Youngchul, & Reitz, 2011)

The graph is presented in the article Modeling the Influence of Molecular Interactionson by (JiaoQi, Youngchul, & Reitz, 2011). As we can see from the graph there is no major change i the intial boiling point of gasoline compared to E10. Althoug if the fuel is keept in temperatures above 38 degrees the evaporation will start.
One possible fault mode can be fuel evaporation inside the tank during the time the engine is running. Due to the compact lightweight design of the product the top of the cylinder and the tank casing is close to each other. If the fuel evaporates inside the tank the pressure will be raised to specified pressure on the pressure valve. In theory, this would increase the fuel delivery of the carburetor pump. If there is a large evaporation of the fuel inside the tank the fuels characteristics will change and this might affect the stability of the engine (JiaoQi, Youngchul, & Reitz, 2011).

3.4.2 Carburetor pump theory

Lack of impulse
The impulse channel from the crank case to the carburetor pump has five different area changes, two minor bends and one major bend, this could cause lower impulse to the carburetor pump at some engine speeds. Due to the different volumes and lengths of the channels some engine speeds/frequencies can be resonant and thereby not providing any impulse signal to the carburetor pump. If the signal is weak it will harm the movement of the membrane inside the carburetor pump and thereby decreasing the fuel flow generated by the carburetor pump. When the fuel flow under the needle seat is lower than the engines fuel consumption the stability of the engine will be heavily affected.

When calculating this kind of problems acoustic formulas is used, the calculations is based on the speed of sound within the fluid or gas. A formula for this kind of calculations is presented in the *National Measurment system Good practices guide to impulse lines for diffrential-pressure flow meters*. The good practices is mentioned for pressure and flow meters but it is about preventing resonance on pulses moving in pipes. To calulate the impulse resonant frequency a lot of different parameters has to be measuerd, temperature within the different channels, velocity of sound in the gas inside a channel and how the sharp bends affect the system. (National Measurment System, 2017)

This would cause a very time consuming and diffcult processes to calulate.
Instead the impulse can be tested with a pressure gauge inside the impulse channel on the carburator. The test should be runn on all different engine speeds to seek if the impulse is affected in a negative way by some engine speed/frequency.

To make such an evaluation a pressureguage, with a high accurcy and high measurement frequency is needed. Due to lack of space close to the carburator a hose for the presuregage is needed. When adding more volume to the channel the pressure can be both decreased and increased due to resonace on some frequencies. Since the engine has a large span of engine speeds the frequencies that will be evaluated are from 130 rps to full speed around 230 rps. To minimizie the risk of affecting the measurment results the length and diameter of the hoses has to be minimized.

Lack of fuel delivery
If the impulse pressure becomes resonant in some frequency the carburetor pumps fuel delivery capacity will be affected.

To measure the fuel delivery to the metering chamber a pressure gauges can be placed under the needle seat to seek if there are pressure drops. In theory the needed pressure just has to be above zero all the time to feed the metering chamber with fuel.

Pressure peaks during an engine cycle

Since the pump is driven by the impulse signal that varies from around -200 mbar to up to 800 mbar the fuel delivery will also have pressure peaks. The pressure peaks could turn the flow into a turbulent flow when opening the needle valve during a peak.

If the flow is turbulent inside the metering chamber the risk of vapor bubbles to occur is larger. If the bubbles are sucked into the fuel control system it will harm the stability of the engine. One way to even the pressure peaks of the fuel flow is to implement a hole in the pump lid to the carburetor. When placing a hole over the needle chamber on the dry side it will be atmospheric pressure below the membrane. In theory, this will lower the pressure peaks and drops thereby creating a more steadier fuel flow to the metering chamber.

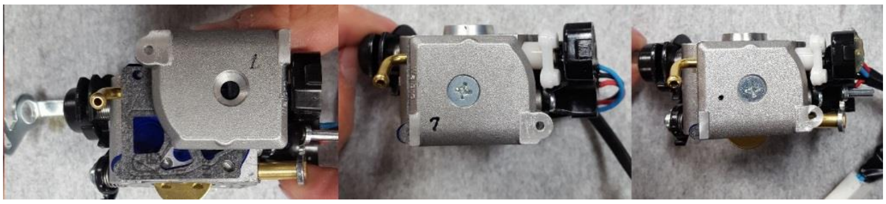


Figure 10 Hole in carburetor lid

Needle seat

One possible fault mode for the stability could be the size of the needle seat. As fuel travels through the needle seat it will lose energy. The narrower the seat is the larger the energy loss will be. With a narrower seat the velocity of the fuel will also increase, after leaving the seat the fuel will be pushed against the needle.

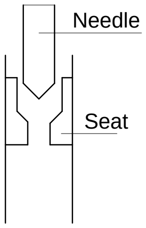


Figure 11 Sketch over needle valve

A narrower needle seat could generate a more accurate fuel flow to the metering chamber with an increased velocity and an increased energy loss. The benefits of a narrower needle seat is a more precise volume but with a higher velocity, this might turn the flow turbulent.

A wider needle seat will deliver a less precise amount of fuel, but with a lower velocity and energy loss. The lower velocity could help the stability of the engine since the delivered fuel to the metering chamber will be more stable.

To evaluate the size of the needle seats affection of the stability, both a 0,7 mm needle seat and a 1,2 mm needle seat will be compared to the already existing 1 mm needle seat.

The reason for the specified measures are the maximum and minimum provided by the supplier.

3.4.3 Metering chamber theory

Placing of takeoff hole

The takeoff hole is where fuel is extracted from the metering chamber to the fuel control system. The takeoff hole's placement in the metering chamber is in the middle of the maximum and the lowest level inside the metering chamber. If fuel start to evaporate inside the metering chamber, the evaporated fuel will rise to the top.
With the placement of the takeoff hole in the middle of the metering chamber, the fuel control system is forced to suck all vapor at once when the vapor level meets the takeoff hole.

If vapor is sucked into the fuel control system the stability of the engine will be affected, the engine will run very lean for some cycles until fuel is extracted again.
To prevent this from happening one solution could be to use two take off holes instead of one. The idea of adding a new takeoff hole to the existing solution is to gradually extract vapor into the fuel control system and thereby not chocking the engine if vapor is sucked in.
In figure 12 the placing of the new takeoff hole is presented.

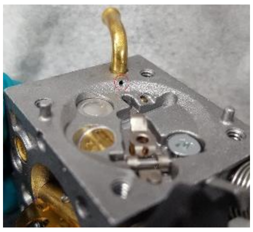


Figure 12 Placing of second takeoff hole

Metering chamber geometry

In the metering chamber fuel flows from the needle valve to the takeoff hole, see the left part of figure 13. The fuel flow on maximum power speed is around 800 grams of fuel per hour. On the way to the takeoff hole, fuel passes through some sharp edges and abruptions.
This will cause a loss of energy and might even cause the flow to be turbulent. If turbulent fuel flow is extracted to the fuel control system it will affect the stability in a negative way, due risk of evaporation (gas bubbles).
To seek if the geometry of the metering chamber affects the stability of the engine a carburetor with a modified metering chamber was built, the modification is shown in figure 13 on the right side
The objective of the modification of the metering chamber's geometry is to lose as little energy as possible, although yet manufacturable.

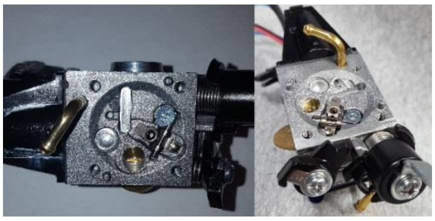


Figure 13 New metering chamber geometry

Metering spring

The stiffness of the metering spring will affect on which fuel level inside the metering chamber the needle valve will open. A lower stiffness on the metering spring will lead to an earlier opening of the needle valve with respect to the fuel level inside the metering chamber, the opposite for a stiffer spring.

A less stiffer spring could help to even the fuel flow between the needle valve and the metering chamber. This would in theory increase the stability of the engine since the flow will be steadier.

When idling the engine, the fuel consumption decreases drastically, this can cause problems with a stiffer spring. The problem is that if the spring is too stiff the needle valve opens too late, and the fuel control system might lack of fuel supply. The result of this is an oscillating engine speed when idling, this harms the drivability of the product.

To seek the springs contribution to the stability both a softer spring and a stiffer spring will be evaluated. Focus will be on the stability but an evaluation of the idle aspects of the engine will also be considered, if the study shows a positive contribution to the stability.

3.4.4 Fuel control system theory

Channel size

Reynolds number

The size of the channel between the Autotune module and the main circuit is about 8,5 mm long and has a diameter of 1,5 mm, with an abruption for the idle circuit and the main nozzle. The fuel consumption of the engine at maximum power speed is around 800 grams of fuel per hour. If the channel is assumed to be a pipe with no abruption for the idle circuit the flow inside the channel can be calculated as well as the type of flow. The formulas needed are the presented in appendix five.
Based on the calculation of the Reynolds number of the flow it is considered to be laminar with a value of 43,6.
As shown in appendix five the Reynolds number can be described as following:

$$Reynolds\ number = \frac{4 * Q}{D * \pi * V_{kinematic\ viscosity}}$$

Equation 3 Reynolds number

Q	Flow
D	Diameter
V	kinematic viscosity

Table 2 Units of Reynolds number

Energy losses

To calculate the loss of energy in the system between the Autotune module and the main nozzle a few assumptions has to be made. One that the idle circuit is fully closed when the throttle is wide open. Two that the case is studied in a one-dimensional study with the center plane in the center of the channel.

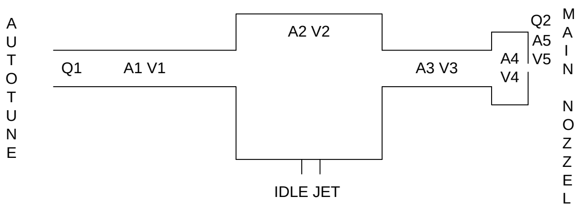


Figure 14 Presentation of calculation model

When calculating the energy loss of the system, it was found that the idle pocket acts as a reservoir. This means that the area of the idle pocket is so much larger than the channels area, if the area of the idle pocket change it will not affect the energy losses. The major loss of the system is in between the area before the main nozzle and the side feed, A3 to A4 in the picture above.

The reason for this is explained in the book A brief introduction to fluid mechanics, it is due to change of direction of the fluid in certain areas (Young, Munson, Okisihi, & Huebsch, 2007). The narrower the channel is that is connected to reservoir the minor the energy losses will be. This is due to the smaller area where the flow of the fluid is redirected. Below in figure 15 a presentation of the phenomenon described in chapter 8 of the book A brief introduction to fluid mechanics is presented.

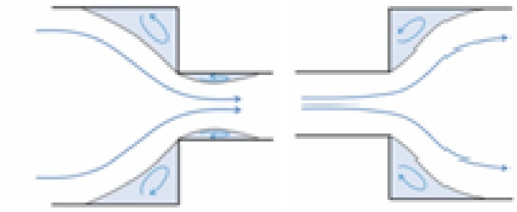


Figure 15 Energy losses in contractions and openings

The calculations of energy losses within the system is presented in a summery at the end of the chapter, for complete calculations refer to appendix five.

Since the energy inside the system can be described as the pressure times the flow, a loss in energy will be a pressure drop since the flow is constant.

Side feed size

The calculations of the energy losses pointed to that the side feed size on the main nozzle with regards to the channel also contributed to the energy losses.
This was also brought up during the startup process of the project that the side feed size often affects the stability of the engine.

Side feed

To fit the required fuel consumption for each engine type, a side feed is used on the main nozzle. The function of the side feed is to feed the engine with the correct amount of fuel when the main circuit is active. The larger the bore of the engine the larger side feed is needed.

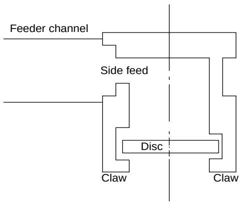


Figure 16 Sketch over main nozzle components

Remote jet carburetor

Another design of a carburetor is a remote jet carburetor that is not explained in the reversed engineering, since it is not applied to the examined carburetor. The remote jet carburetor operates in the same function as the examined carburetor with one exception, the main nozzle has two openings and the side feed is moved to a jet between the idle circuit and the main circuit. In figure 17 a graphical presentation of the carburetor is presented.

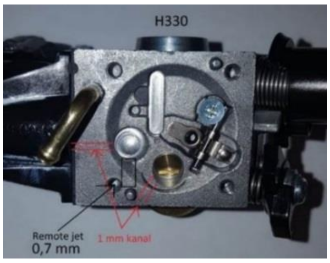


Figure 17 Explaining picture of remote jet solution

On previously designed carburetors at Husqvarna this design has increased the stability of the engine. The examined carburetor presented in figure 17 uses two openings of 1,2 mm on the main nozzle and a small remote jet of 0,7 mm to control the fuel.
A down side of the remote jet carburetor is that the fuel has to travel longer distances from the Autotune to the main nozzle. This could harm the acceleration of the engine, since it will create a longer channel and there by a greater lag between Autotune and the main nozzle. The acceleration of the engine is a very fast sequence from idle around 50 rps to maximum engine speed in around 600 ms.

Summary of energy calculations

There is some limitation to the side feed size and the channel size due to Autotune and the manufacturability of the carburetor. On the existing design of the carburetor the side feed size has to be around 0,6-0,7 mm. For the channel size the supplier of the carburetor has agreed to manufacture the carburetor with as narrow channels as 1 mm. If they were to push the channel to an even narrower size the quality and tolerance of the carburetor cannot be guaranteed.

With regards to the limitations of sizes on both the channel and the side feed, calculations were made. The calculations are for the standard channel and the narrowest channel possible combined with the largest and smallest side feed available.
Furthermore the remote jet carburetor setup was calculated with one side feed size of 1,2 mm. Since the built analysis is a one-dimensional model, the contribution of two side feeds could not be evaluated. Although calculating it with only one side feed, shows a large decrease of the energy losses compared to a regular side feed sizes.

Channel size	Side feed size	Energy loss in Joule
1,5 mm	0,6	0,006181
1,5 mm	0,7	0,005778
1 mm	0,6	0,0012021
1 mm	0,7	0,001144
1 mm	1,2 remote jet	0,0001355

Table 3 Summery of energy calculations

If we analyze table 3 we can see that the side feed size affects the energy loss but far from the effect of change channel size. The decrease of energy loss between 0,6 side feed and 0,7 side feed is just over 5 %. With this low energy loss, it will be hard to evaluate if it has any effect of the engine stability. When evaluating the change of channel size the energy loss is decreased with around 500 %.

This is a major changeover in the energy loss and should be measurable. If evaluating a remote jet with a 1,2 mm side feed, the energy loss would decrease with almost 900% compared to the most optimal selection of channel and side feed size in table 3.

Length of the main nozzle

On the examined carburetor half of the main nozzles outlet is blocked by the venturi, see explaining picture below.

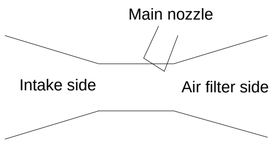


Figure 18 Sketch over main nozzle placement

The placing of the main nozzle might harm the stability of the engine, since the fuel extraction from the nozzle could be harmed due to obstruction by the venturi wall. The placing can also be very effective if there is a turbulence created around the main nozzle and thereby extracting the fuel out of it. If that is the case the fuel will have a very good mixture with the air and affecting the stability in a positive way.

One way to improve the stability of the engine could be to lower the main nozzle down into the venturi. The reason is that the maximum flow speed is in the center of the venturi, so moving the main nozzle down would create a better extraction of the fuel from the main nozzle. A down side of moving the nozzle down in the venturi is that the cross-section area decreases this could harm the power output of the engine.

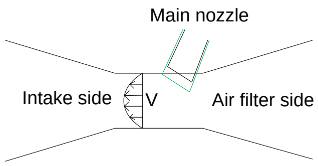


Figure 19 New placement of main nozzle

4 RESULTS

During this chapter, the results from the practical testing of the previously discussed theoretical aspects are presented as well as the results from the benchmark. The layout of the chapter starts with a presentation of the results of each sub system, later follows a discussion of the presented result. At the end of the chapter the carburetor improvements are presented and discussed. Where no contribution to the stability could be measured the results has been screened to generate space for the interesting findings.

4.1Results from fault mode analysis

4.1.1 Fuel tank analysis results

Pressure valve

From the theoretical analysis, it was found that if the pressure increases so does the pump function, if the valve does not open to underpressure the pump will eventually stop working. To test if the pressure valve was a possible fault mode it was removed allowing the constant atmospheric pressure within the tank.

There was only a minor change in the stability of the engine with the pressure valve removed, found during the warmup state of the engine. To be more precise it only affects the stability during the first 15 seconds of operating time.

Operating temperature

To seek the maximum operating temperature of the tank when the engine is running, thermal wires was placed on the fuel filter. The measuring was conducted during a stability evaluation, the maximum temperature was 36 degrees after the load cycle, conf appendix one page 2.

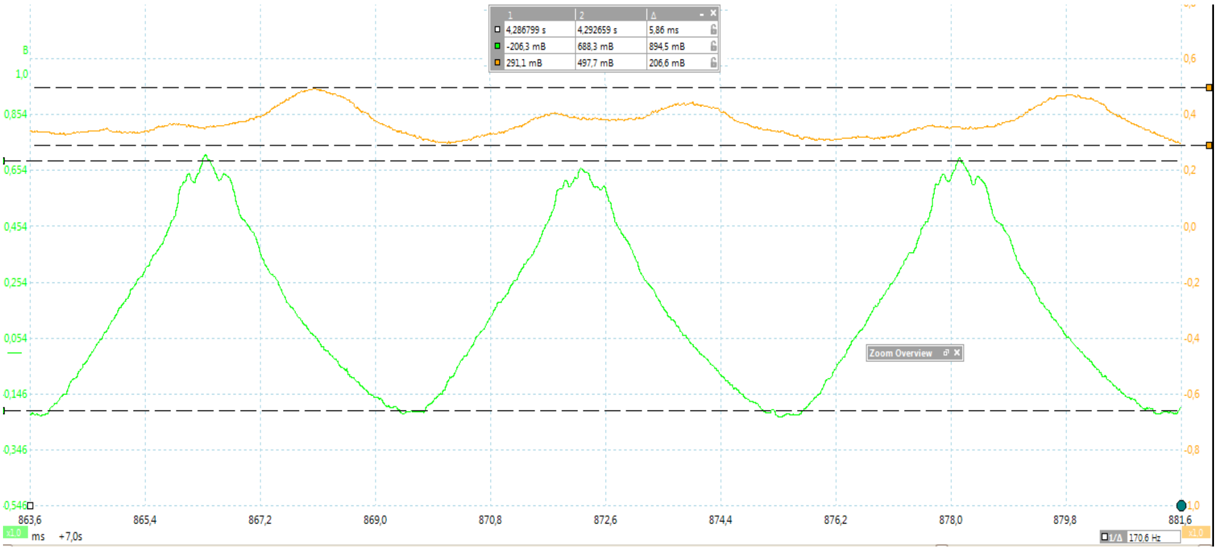
4.1.2 Carburetor pump analysis results

Results of impulse and fuel pressure

To measure the impulse and fuel pressure two Mesa EPB-C11_1B-/4LM pressure gauges an amplifier and a digital oscilloscope was used. The pressure gauges measures pressure from -1 bar to +1 bar and with a measurement frequency of 5µs. The digital oscilloscopes sampling speed was set to 200 k samples per second and a sampling interval of 5µs.

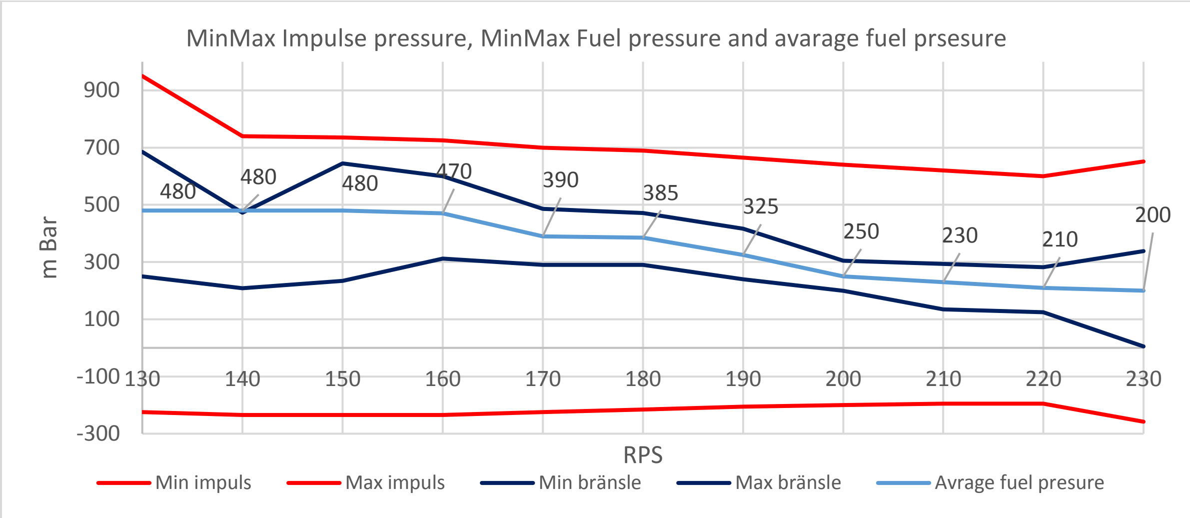
Findings of the measuring

In the graph 1 the fuel pressure is plotted in orange and the impulse pressure in green.
The impulse pressure is linked to the pressure inside the crank case, during decompression it reaches around -200 mbar and during compression it reaches around 700 mbar, measured at 170 rps. This drives the carburetor pump membrane up and down creating a pressure under the needle valve. The pressure peak of the fuel flow has a lag of around 1,5 ms due the travel length between the pump chamber and needle valve.



Graph 1 Impulse and fuel pressure at 170 rps

To further investigate the impulse and fuel pressure, the pressures was measured from 130 rps to 230 rps. The results are presented in graph 2, the min and max levels of impulse pressure is plotted in red, the min and max fuel pressure is plotted in dark blue and the average fuel pressure in light blue.



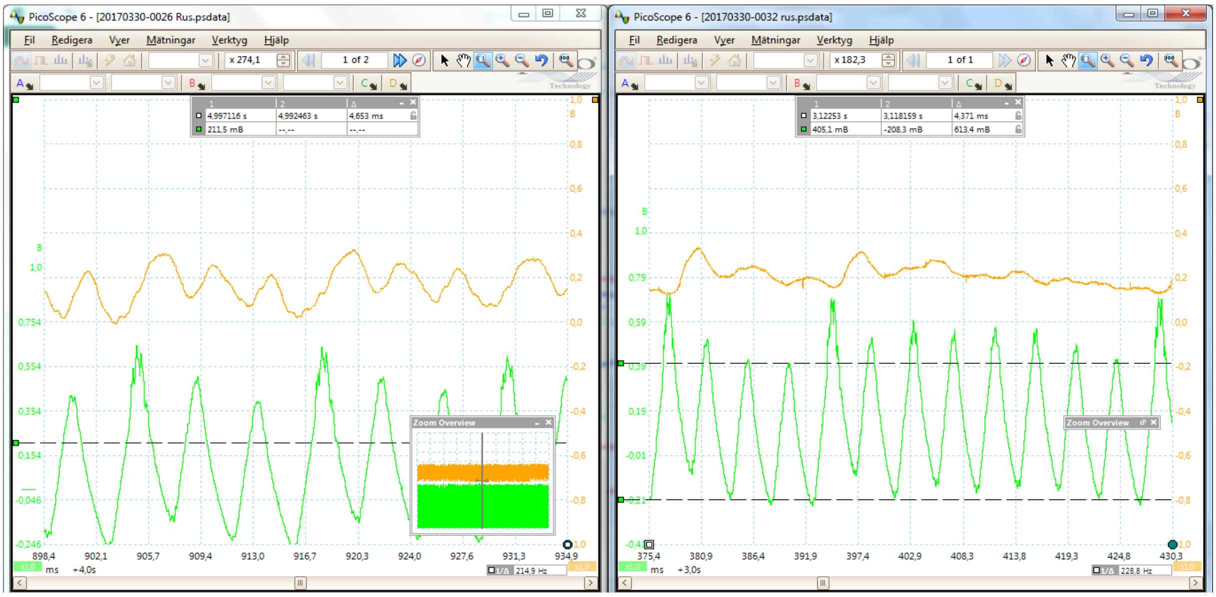
Graph 2 Impulse and fuel pressure during different engine speeds

Results of atmospheric pressure under needle chamber

To evaluate the solution, the engine was ran at maximum speed around 230 rps. At this speed there is a spark elimination to limit the engine speed. As the sparks are eliminated the impulse pressure decreases as well as the fuel pressure.

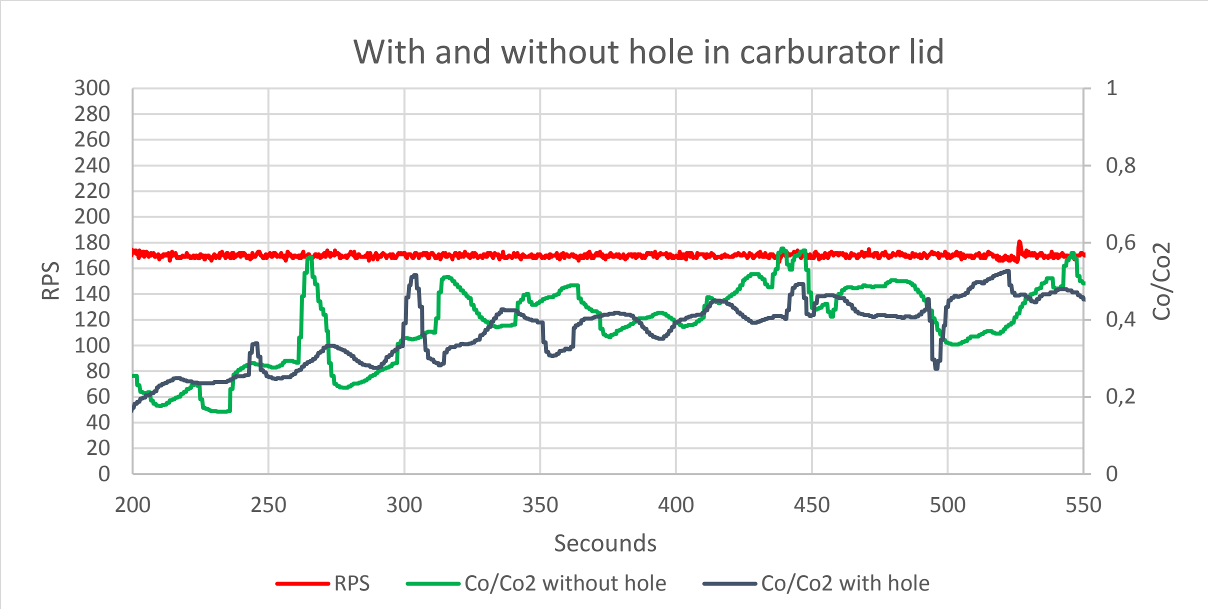
In graph 3 to the left is the standard solution where the lid acts as a sealed volume over the needle chamber. In graph 3 to the right is the results if the needle chamber has atmospheric pressure.

As we can see in graph 3 when atmospheric pressure to the needle chamber is applied the pressure do not drop down during spark elimination.



Graph 3 Presentation of atmospheric pressure under the needle seat

To further evaluate the contribution to stability on maximum power speed a carburetor with and without a hole in the carburetor lid was evaluated. In graph 4 and table 3 the results of the evaluation is presented.



Graph 4 Results of hole in carburetor lid

The sample for the standard deviation is taken between 300 and 500 seconds.

Type of lid	Standard deviation
Without hole	0,05593324
With hole	0,04716122

Table 4 Results of carburetor lid

Results of needle seat

As stated in the theoretical analysis three different needle seat where evaluated a 0,7 mm, 1mm and 1,2 mm. The findings of the changing of needle seat where that they do not affect the stability in any measurable way.

4.1.3 Metering chamber analysis results

Results of two takeoff holes

The evaluation of the second take off hole did not show to affect on the stability.

Metering spring

To evaluate the metering springs contribution to the stability three different springs where evaluated. A standard of specifying the stiffness of the spring provided by the supplier where the weight/force generated when compressed to 7,2 mm. The three different springs evaluated was 22 gram, 29 gram and 32 gram. The examined carburetor operates with a 29 gram spring in the current setup. There was a minor effect on the stability with regards to different metering springs.

All the data presented in table 4 is collected from the same engine and carburetor, only the metering spring has been changed. The data is compared with the standard deviation of the Co/Co^2 variation as presented under heading 2.5 Definition of stability.

Weight	Variation of Co /Co^2
22 g	0,060562
29 g	0,054678
32 g	0,058734

Table 5 Results of spring stiffness

Results of metering chamber geometry

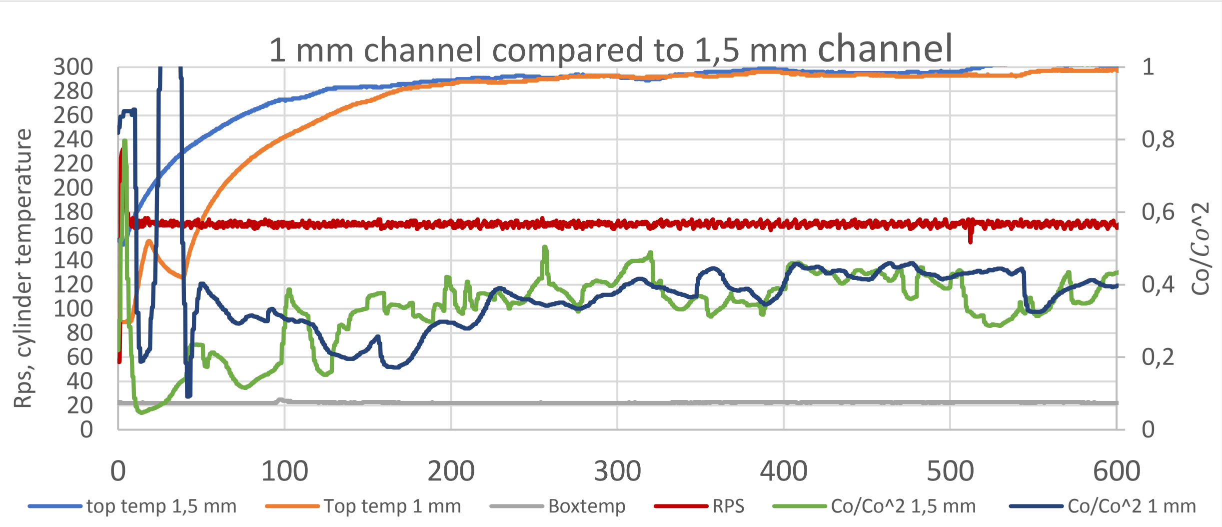
During the analysis of the modified metering chamber no change of the stability was found.

4.1.4 Fuel control system analysis results

Results from channel size

During the theoretical analysis of the fuel control system calculation of a major decrease in energy loss was presented. The energy loss was decreased by changing the diameter of the channel between Autotune and the main nozzle from 1,5 mm to 1 mm. The saving in energy loss was around 500 %.

To evaluate how this affect the stability small pieces of a 1,5x1 mm tube was fitted inside the channel, decreasing the diameter to 1 mm. Below is a graph 5 the results is presented, the carburetor with 1,5 mm is presented in green and the 1 mm in blue.



Graph 5 Different channel sizes

To evaluate the stability, change a sample of the variation between 250 to 450 seconds was evaluate. The outcome of the evaluation is presented in the table 6.

Type of carburetor	Standard deviation
1,5 mm channel	0,044544
1 mm channel	0,035896

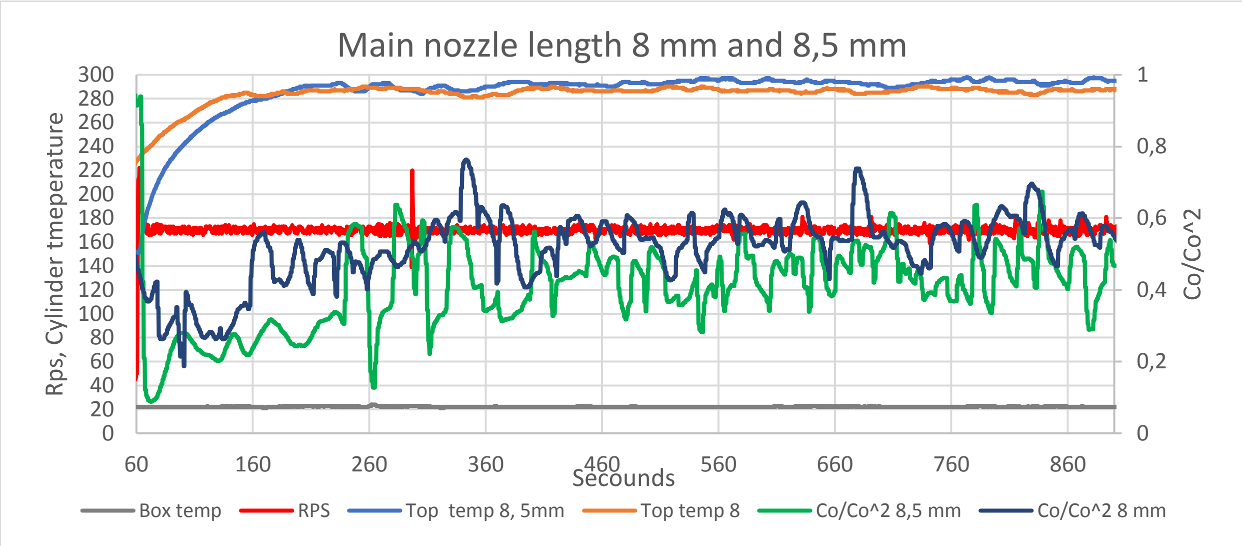
Table 6 Results of channel size

As we can see from table 6 the1 mm channel carburetor generates a more stability.

Results from length of main nozzle

During the analysis of the fuel control system it was found that the placing of the main nozzle might obstruct the fuel flow out of the main nozzle. To further analyze this a new main nozzle was fitted that locates the main nozzle as presented in figure 19. The testing was conducted with the previously stated procedure to analyze stability.

Below in graph 6 the standard 8 mm main nozzle is presented in green and the new 8,5 mm main nozzle in dark blue. The sample for the stability is calculated in the interval 400 to 600 seconds.



Graph 6 Different length of main nozzle

Main nozzle length	Standard deviation
8,5 mm	0,049264
8 mm	0,060014

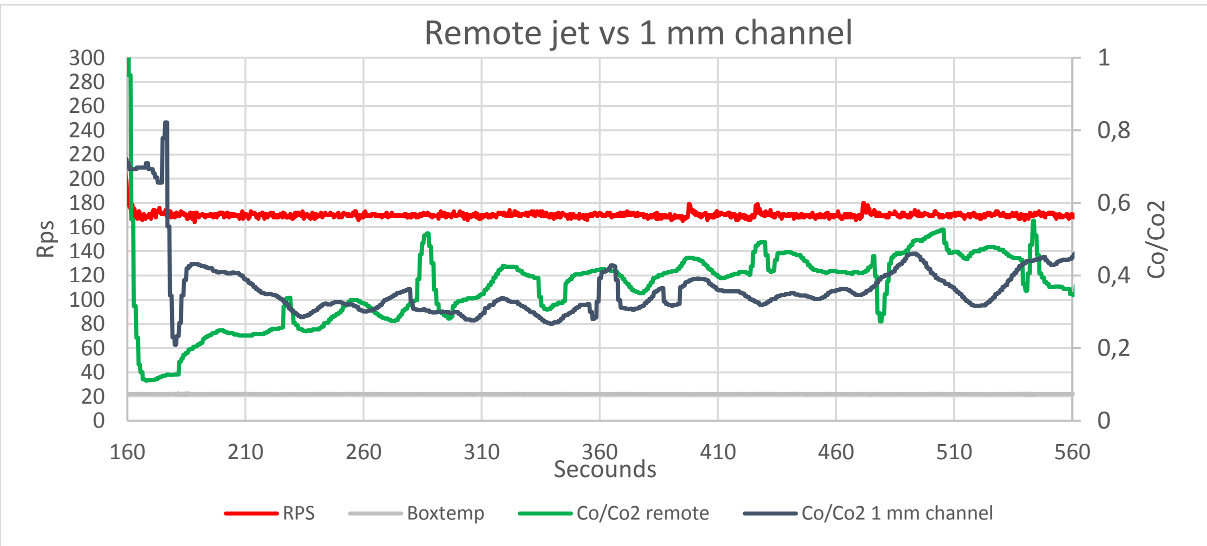
Table 7 Results of main nozzle length

Results from remote jet

The remote jet carburetor for the analysis was built with the same specification as the recommended carburetor.

- 8,5 mm main nozzle
- Hole in the carburetor lid under the needle chamber
- 1 mm channel between Autotune and the main nozzle

The reference during the test was a carburetor with the recommended improvements. The timespan where the standard deviation sample is taken is between 300 to 500 seconds.



Graph 7 Evaluation of remote jet and recommended carburetor

Carburetor type	Standard deviation
Remote jet	0,045435
Recommended carburetor	0,044591

Table 8 Results of carburetor type

4.2 Results from benchmark of competitive carburetor

During the benchmarking process the competitor carburetor was evaluated against the already established reversed engineering structure of the examined carburetor. The objective was to seek the differences of the carburetors. To receive a good structure of the results it is presented in the four different sub systems.

4.2.1 Fuel tank

During the analysis of the fuel tank no variation in the function or construction of the two compared tank where found.

4.2.2 Carburetor pump

During the analysis of the carburetor pumps two differences was found, the impulse and the volume of the pump.

Impulse

The impulse channel has less bends and changeover in cross-sectional areas which in theory will lead to a less resonant impulse signal. Furthermore the placing of the impulse is in the carburetor lid just below the membrane, this might lead to better pump function.

Pump volume

The volume of the pump chamber on the analyzed competitor carburetor was larger than the examined carburetor. This would in theory increase the fuel flow if the impulse signal can handle the larger volume.

The conclusion that can be made from the analysis is that the competitor probably has a larger fuel flow capacity than the examined carburetor. Since there is no need for a larger pump on the examined carburetor according to the measurements conducted, the competitors carburetor might have some problems that causes lower fuel deliver, thereby are in need of a larger pump.

4.2.3 Metering chamber

The major difference between the two metering chambers is that the competitive carburetor has its takeoff hole in the very top of the metering chamber. This will force the carburetor to directly extract all vapor at once if it occurs. The testing conducted on the examined carburetor with two takeoff hole did not generate any more stability. It is possible that the placing of the takeoff hole has some advantage when running the engine in very warm climate.

4.2.4 Fuel control system

The major differences with the fuel control system is the length of the channels transporting the fuel and the placing of the fuel control valve. The placing of the fuel control valve is just above the venturi, it is 5 mm lower compared to the examined carburetor. This could help preventing vapor to be extracted by the fuel control system since it is further down in the carburetor body. The length of the channels should not affect the energy losses in a major way according to the calculations presented in appendix five.

The HL major that represent the energy losses linked to length of the channel is very small compared to HL minor which represent energy losses due to cross sectional area changes.

4.3 Discussion

4.3.1 Fuel tank

- Pressure valve

Since the gain in stability was so minor and with a changing cylinder temperature during the warmup of the engine no further examination was conducted.

- Evaporation

The highest temperature of the fuel inside the tank was measured to be 36° C, thereby no evaporation of the fuel will occur in the tank. The evaluation was conducted in the controlled environment for stability evaluation, if the engine is ran in a warmer climate it is likely that the fuel will start to evaporate inside the tank.

4.3.2 Carburetor pump

- Impulse and fuel pressure

As we can see from graph 2 the minimum fuel pressure decreases as the engine speed increases, yet it still fulfills the demand of never being a negative pressure. Other findings are that the decompression seems to be decreasing with an increasing engine speed, until the engine reaches the maximum speed which is controlled by elimination of sparks to keep the speed down. This could be caused by blow-by on higher engine speeds, blow-by is a leakage between the combustion chamber and the crank case. This also explains why the decompression increases when reaching maximum speed. Since the sparks are eliminated to keep the engine speed down so is the pressure that can leak from the combustion chamber to the crankcase.
Another crucial aspect to mention is that the values measured should not be seen as absolute values, this is due to the extra volume added when installing the pressure gages. The extra volume could harm the measurement, yet in a very small way (National Measurment System, 2017).

- Atmospheric pressure under needle seat

As we can see in the graph 3 when atmospheric pressure to the needle chamber is applied the pressure do not drop down during spark elimination. This will give the engine a more stable fuel supply and thereby increase the stability of the engine. There is similar effect on maximum power speed but it is not as obvious as on maximum engine speed. Therefore, graph 3 is at full engine speed to visualize the effect of the improvement.
To further analyze the stability contribution of the changeover an evaluation of the two different carburetor lids was conducted. In graph 4 the results is presented, as presented in table 3 the hole in the lid increased the stability with around 15 %.

- Needle seat

The findings where that the size of the needle seat does not affect the stability. This indicates that the stability is not affected by the needle seat size on maximum power speed, therefore not further investigation was conducted.

It is possible that the smaller needle seat does not enable the needed fuel flow on maximum engine speed.

4.3.3 Metering chamber

- Two take off holes

With this knowledge, a conclusion can be made that there is very unlikely to be a large amount of vapor in the metering chamber when the carburetor operates. The solution could be affecting the stability in a positive way if the engine operates in a warmer climate.

- Metering spring

As presented in the table 5 there is a variation of the stability with regards to the stiffness of the spring. Although the best stability was gained with the already applied spring, a 29 g spring. Conclusion made from this is that the spring selection is already optimized for maximum stability.

- Metering chamber geometry

Since the geometry did not change the stability the loss off energy is very minor. The conclusion made is that the geometry of the metering chamber does not affect the engine stability.

4.3.4. Fuel control system

- Channel size

When comparing the results between the 1 mm channel and the 1,5 mm channel the 1 mm channel is 24% more stable when evaluating the variation. Furthermore, the 1 mm channel does not have the same rapid deacceleration of the Co/CO2 levels, this is known as lean peaks. A lean peak is when the engine gets too low fuel flow, this will increase the cylinder temperature thereby shorten the life time of the engine as well as increase the emission rate (Ghazikhani, Hatami, Safari, & Ganji, 2014).

- Main nozzle length

When evaluating the results in graph 5 and table 6 an increase in stability by 22% with the 8,5 mm nozzle is presented. There is also a decrease of lean peaks with the 8,5 mm main nozzle same as found with the 1 mm channel.
As stated during the theoretical analysis there might be an decrease of the engine power due to smaller venturi size. This was tested with a dyno in the engine lab. The results conclusion where no change of the power output with regards to the main nozzle size.

- Remote jet

During the evaluation of the remote jet carburetor it was compared to a carburetor with the recommended product improvements. This was to evaluate if the remote jet carburetor will generate a better stability than the recommended carburetor. In graph 7 the results of the measurement is presented, in table 7 the variation is presented. As presented in table 7 the variation is very small and it is hard to tell which one that is the most stable.

To further evaluate the remote jet carburetor other aspects than stability must be evaluated such as manufacturability, engine performance and risk. This is not included during the aim of the thesis, thereby a brief presentation of the aspects are presented in appendix seven.

The conclusion of the results from appendix seven is that the recommended carburetor is likely the best choice due to:

- Better manufacturability
- Better engine performance
- Less risk of leakages

4.4 Recommended product improvements

The recommended product improvements are presented below with a short summary of benefits and potential risks.

- 1 mm channel instead of 1,5 mm channel between Autotune and the main nozzle

When measuring the difference in stability of the 1 mm channel compared to the 1,5 mm channel the 1 mm channel improves the stability with around 20%.

Furthermore the 1 mm channel increases the speed inside the channel and should thereby increase the acceleration speed of the engine.
The major risk to evaluate is the tolerances that the supplier can provide and seek how it affect the engine performance. The tolerances were the same as for the 1,5 mm channel but the smaller channel might affect the engine more with regards to the tolerances.

- 8,5 mm long main nozzle instead of 8 mm.

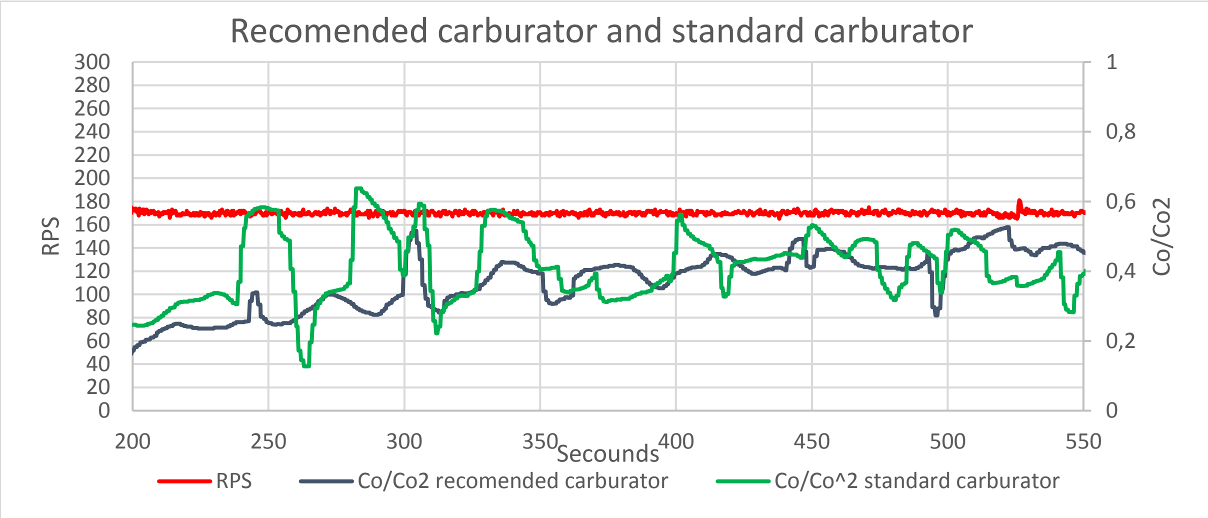
The 0,5 mm longer main nozzle increased the stability with around 20%. A major benefit of the changing of main nozzle is that it is a standard part and thereby very easy to implement. The major risk of implementing the longer main nozzle is that the cross-sectional area of the venturi decreases. This might harm the power output of the engine, to secure it does not harm the power output an evaluation with a dynamo was conducted. The results showed that the new main nozzle does not affect the power output of the engine.

- A 2 mm hole in the carburetor lid below the needle chamber

As presented during the discussion the implementation of the hole in the carburetor lid will increase the stability with around 15%. The cost of implementing the hole is very minor since it could be done directly in the die-mold. The major risk involved would be if sharp items under 2 mm will get into the hole and puncture the pump membrane. Since the carburetor is mounted in a sealed area where only fresh air is blown in, this is very unlikely to occur. Furthermore, this is already implemented on other carburetors both from internal and external sources.

4.4.1 Gained stability improvement of the recommended carburetor

To finalize the evaluation of the recommend carburetor it was evaluated against the standard carburetor. In graph 8 the results of the recommended carburetor is presented, note that there are only one lean peak with the recommended carburetor against 7 of them with the standard carburetor.



Graph 8 Results of the stability gain

In table 8 the difference between the stability is presented, as presented the recommended carburetor is around 40 % more stable than the standard.

Type of carburetor	Standard variation
Recommended	0,04716122
Standard	0,0802027

Table 9 Gain in stability

5 CONCLUSIONS

During this chapter, the conclusions made from the thesis with regards to the research question is presented.

5.1 Stability

The research question of the stability was, what contribution does the events occurring prior to the combustion have to the engine stability?
This has been investigated by establishing a system understanding of the complete engine with focus drawn to events prior the combustion see heading 3.3 fault mode finding.

A fault tree of potential fault modes affecting the stability has been constructed see figure 6. All the fault modes have been evaluated in theory and tested in practice. Below is a list of the found attributes during this thesis that affect the engine stability.

- Atmospheric pressure under needle seat
- Metering spring
- Channel size
- Main nozzle length
- Remote jet carburetor design

Furthermore the reversed engineering documents and system maps created during the thesis will be implementable for other projects where system understanding of the carburetor is needed.

5.2 Recommended carburetor

The second research question was, can simple modifications to an already designed carburetor increase the engine stability?

The answer to this question would be yes with the results generated from the thesis.
The conclusion made is that with the three following simple and implantable improvements, the engine stability can be increased by 40%.

- Channel size

Changing the channel size is a quite simple task that only involves change of one single tool in the manufacturing process.

- Main nozzle length

Changing the main nozzle is a very simple task since it is a standard part from the supplier.

- Hole in the carburetor lid

Implementing a hole in the carburetor lid is also a simple task, this could be done directly in the die-mold.

5.3 Recommendation to future activities

- Investigate the aspects of takeoff hole placement in warmer climates

Since it was found the competitor carburetor uses a takeoff hole placed on the highest possible level inside the metering chamber, it might generate some positive aspects not found during the stability analysis. It might be helpful when starting the engine or when operating the engine in warm climates, 38° C and above.

- Seek a deeper understanding between the energy losses in the fuel control system with regards to the stability

During the thesis, not much effort was spent on trying to seek a deeper understanding of the relation between energy loss and stability, the reason is that it was not involved in the aim of the thesis. It could be of great use for further new development of carburetors to truly understand the relationship between energy losses and engine stability.

6 CRITICAL REVIEW

During this chapter the results of the thesis is reviewed in aspect of environment, health, safety, society and economic. It also involves a review of the work that has been conducted during the thesis

6.1 Environment

For the engine to become more environmental friendly the stability has to be increased and thereby lowering the operating temperature. With the recommended carburetor E10 can easily be the fuel source to the engine without increasing the emissions due to less stability.
When running the engine on E10 both the Co_2 foot print and the NOx and Hc levels of the emissions is lowered. This will lower the strain on the environment.

6.2 Health, safety and society

When lowering both the HC and NOx levels produced by the engine the environment for the operator of the engine will be better. This is due to that the operator will be exposed to less harmful substances, thereby increasing both the health and safety for the operator. With an increased health and safety for the operators of the engine the society will also be benefited.

Some cases where the benefits might show is less occupation of medical care, more healthy inhabitants and thereby larger tax income. Furthermore, less emissions will create a more sustainable society with regards to the environmental aspects mentioned before.

6.3 Economic

The changes recommend will probably come with an increased cost of producing the carburetor, and thereby an increased part price. When comparing the cost to the problems that could occur when running E10 in the engine, the cost seems very minor. One crucial aspect to add to the cost is that the user of the engine will experience a better drivability.

6.4 Conducted work

The methods applied during the fault finding part of the thesis have generated a good and structural foundation. If more time would have been present, some logical gates could have been applied in the fault three, this might have shortened the time of evaluating the basic events.

The model build for energy loss calculations is basic, although it has helped with the selection of sizes within the carburetor. The model has been validated with live testing on the product.

When working with measurements there are always measurement uncertainties to consider. During the thesis a wide range of actions has been taken to prevent as much uncertainness as possible.

During the thesis it was found that the evaluation of two takeoff holes needed evaluation in warmer climates. This was not within the scope for the thesis and thereby screened from the thesis. There is a possibility that a better predictivity during the startup process would have caught the need.

REFERENCES

Andersen, B., & Fagerhaug, T. (2006). *Root Cause Analysis simplifed tools and techniques.* Milwaukee: American Society for Quality.

Bill, V. (den 10 March 2017). *NASA.* Hämtat från NASA HQ: https://www.hq.nasa.gov/office/codeq/risk/docs/ftacourse.pdf

Biofuels association of Australia. (den 4 April 2017). *Biofuels association of Australia*. Hämtat från http://biofuelsassociation.com.au

Boulanger, J.-L. (2014). *Formal Methods Applied to Industrial Complex Systems.* London: Wiley.

EU. (den 26 03 2017). *www.ec.europa.eu*. Hämtat från European comission: https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels

Evan, J. R., & Lindsay, W. M. (2014). i *Managing for quality and preformance excellence* (ss. 647-648). South-Western Cengage learning.

Ghazikhani, M., Hatami, M., Safari, B., & Ganji, D. (2014). Experimental investigation of exhaust tempreature and delivery ratio effect on emissions and preformance of a gasoline-ethanol tow-stroke enigne. *Case studies in thermal engineering 2,* 82-90.

Huang, W., Hongbo, F., Yongfu, Q., Zhiyu, C., Pingru, X., & Yu, Q. (2016). Causation mechanism analysis for haze pollution related to vehicle emission in Guangzhou, China by employing the fault tree approach. *Chemosphere,* 9-16.

JiaoQi, Youngchul, R., & Reitz, R. (2011). Modeling the Influence of Molecular Interactions on. *SAE International.* Madison.

Krishna B, M. (2008). *Handbook of performability engineering* . London: Springer.

National Measurment System. (den 7 March 2017). *Tuvnel.* Hämtat från www.Tuvnel.com: http://www.tuvnel.com/_x90lbm/Impulse_Lines_for_Differential-Pressure_Flow_Meters.pdf

Ullman, D. (2010). *The Mechanical Design Process.* Boston: Mc Graw Hill Higher Education.

Vasilije, K., & Kees, D. (2016). The art of 'stepping back': Studying levels of abstraction in a diverse design team. *Design Studies Volume 46,* 79-94.

Wasson, C. S. (2016). *System Engineering analysis, design, and devlopment.* New Jersey: John Wiley & Sons, Inc.

Young, D., Munson, B., Okisihi, T., & Huebsch, W. (2007). *A breif introduction to fluid mechanics 4th edition.* Phoenix: John Wiley & Sons, Inc.

APPENDIX ONE

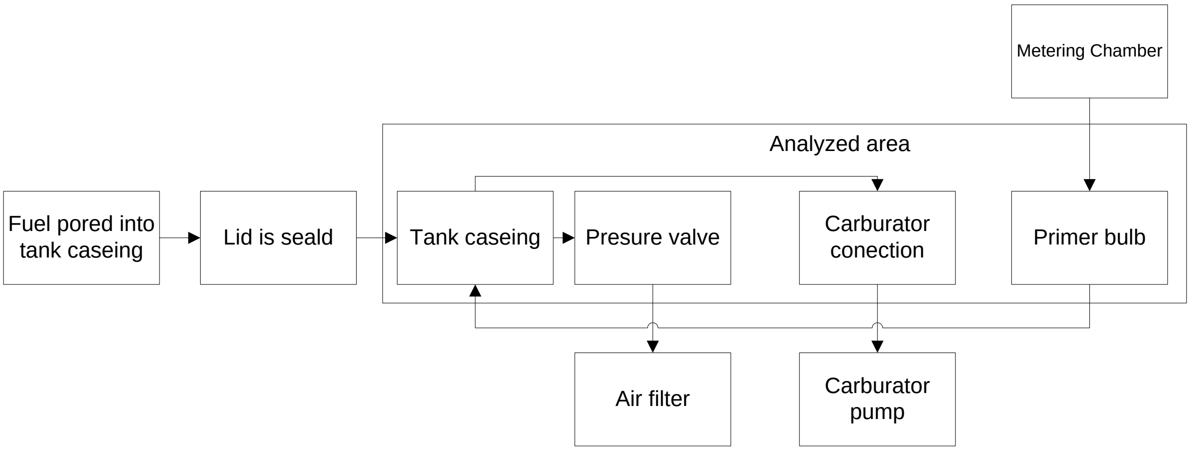
Reverse engineering of fuel tank

Design Organization: Husqvarna AB | **Date: 29/01-2017**

Product Decomposed: Fuel tank to a 40 cc engine

Description: A sealed container with a regulated pressure storing fuel for the carburetor.

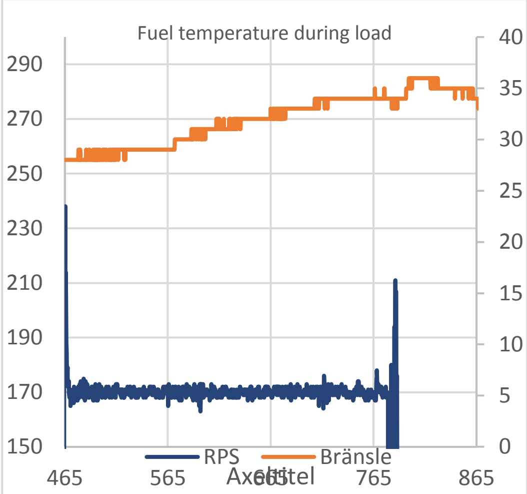
How it works: Fuel is poured in to the tank and sealed with a lid. The pressure within the tank is controlled with a pressure valve. The fuel is fed into the carburetor through a fuel filter connected with a hose on to the carburetor. The tank also has a connection to the metering chamber through a primer bulb.



Interfaces with other objects:

Part #	Part Name	Other object	Energy flow	Information Flow	Material Flow
1	Tank casing	Cylinder top	Fuel is poured in to the tank and sealed with a lid.	As the tank is a sealed volume pressure within the tank will change with the temperature level. A pressure can also be built up by using the primer bulb connected to the metering chamber on the carburetor.	The lid seals the tank after refueling

2	Pressure valve	Fuel, air filter	When the pressure reach a certain level the valve open, the valve is a two-way valve always open to under pressure.	When the temperature of the fuel increases, the fuel starts to evaporate and a pressure will be built up. The pressure is also affected by the primer bulb. The release of the valve is located in the air filter.	Fuel is heated by the surrounding temperature. The primer bulb is used.
3	Carburetor connection	Fuel pump, hose, fuel filter, fuel	Fuel is extracted from the tank by the pump in the carburetor, passing through a fuel filter connected to the fuel feed on the carburetor by a hose	When the pump is operating fuel is sucked out of the tank and filtered through a fuel filter. If the pumps back valve does not function correctly fuel can bleed back to the tank	The pump is activated and starts to extract fuel from the fuel tank to the carburetor
4	Return from primer bulb	Primer bulb, fuel	To fill the pump and metering chamber on the carburetor a primer bulb is used. The primer bulb works as a pump and removes fuel, vapor or air from the carburetor and replaces it with fresh fuel from the fuel tank.	When pushing the primer bulb the fuel in the bulb is extracted from the bulb to the fuel tank, the fluid or gas in the carburetor is moved to the purge bulb. The bulb has a back valve only allowing fuel to flow from the carburetor to the tank	The primer bulb is used by the operator.

Flow of Energy, information and materials				
Part #	Part Name	Interface part	Flow of energy, information, material	Image
1	Tank casing	2,3,4		
2	Pressure valve	1	NA	
3	Carburetor connection	1,3	NA	
4	Return from purge	2,3	NA	

Links and drawing files:

The Mechanical Design Process Designed by Professor David G. Ullman

 Form # 17.0

APPENDIX TWO

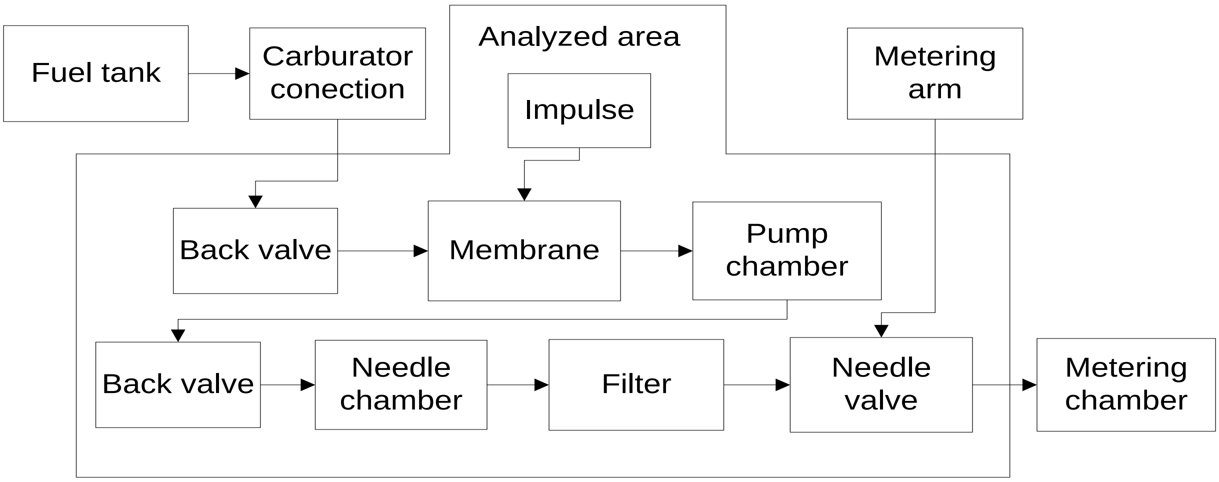
Reverse engineering carburetor pump

Design Organization: Husqvarna AB | **Date: 29/01-2017**

Product Decomposed: Pump function on carburetor.

Description: A membrane pump using the compression and decompression in the engine.

How it works: During a full cycle of an engine the crankcase will have both a compression and a decompression stage. The impulse generated from the engine is used to move a membrane up and down, forcing fuel towards a chamber. In order not to lose fuel flow in the pump two back valves are applied one between the fuel feeder and pump chamber and the other one between the pump chamber and the needle chamber.



Interfaces with other objects:

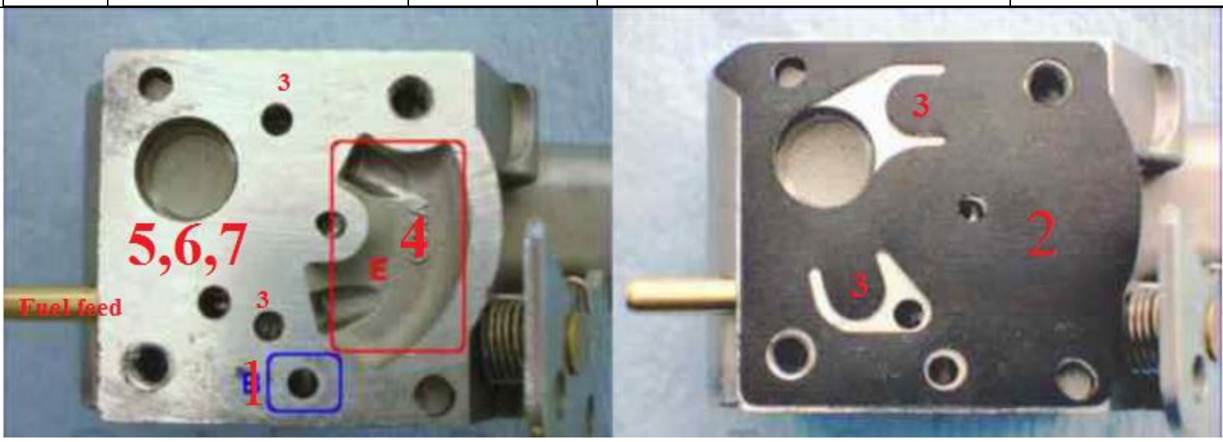
Part #	Part Name	Other object	Energy flow	Information Flow	Material Flow
1	Impulse	Crankcase , Impulse channel	During the engine cycle both a compression and decompression will occur.	The impulse uses the compression and decompression to move the membrane up and down.	The engine completes a full cycle.
2	Membrane	Pump body, Lid	The membrane is affected on the dry side by the impulse. On the wet side, it is in contact with the fuel.	Membrane is forced out from the surface during decompression and forced in during compression. This combined with a chamber of fuel will create a pump.	Membrane extract fuel from fuel tank to the needle valve through the pump chamber and

					the needle chamber.
3	Back valve	Pump body	Two back valves are used to prevent back bleeding to the fuel tank and to the needle chamber.	The valve is a part of the membrane, always open during decompression and closed during compression.	Impulse affect the back valve
4	Pump chamber	Membrane, back valve	A chamber is used as a reservoir to store fuel for the pump.	The pump chamber is a volume that is pumped to the needle valve chamber through a back valve by the membrane	The membrane forces fuel out to the needle valve chamber and feeds with new fuel from the fuel feed
5	Needle chamber	Back valve	A chamber used to store a fuel reservoir for the metering chamber.	A chamber under the needle valve is used to secure fuel flow to the metering chamber.	Fuel is pumped from the pump chamber through a back valve to the needle chamber and extracted by the metering chamber
6	Filter	Needle chamber,	A filter is installed between the needle valve and the needle chamber	The filter is used to filter particles missed by the fuel filter	Fuel is filtered between the needle chamber and metering chamber
7	Needle valve	Metering chamber, needle chamber	A valve constructed by a needle and a seat is used between the needle chamber and the metering chamber.	To not flood the metering chamber a needle valve is used to control the fuel flow. The needle is operated by a membrane and a metering arm within	Fuel is extracted from the metering chamber forcing the metering arm to open the

				the metering chamber	needle valve to fill the metering chamber.

Flow of Energy, information and materials

Part #	Part Name	Interface part	Flow of energy, information, material	Image
1	Impulse	2,3,4	NA	NA
2	Membrane	1	NA	NA
3	Back valve	1,3	NA	NA
4	Pump chamber	2,3	NA	NA
5	Needle chamber	3,6,7	NA	NA
6	Filter	5,7	NA	NA
7	Needle valve	6,6	NA	NA



The Mechanical Design Process Designed by Professor David G. Ullman

 Form # 17.0

APPENDIX THREE

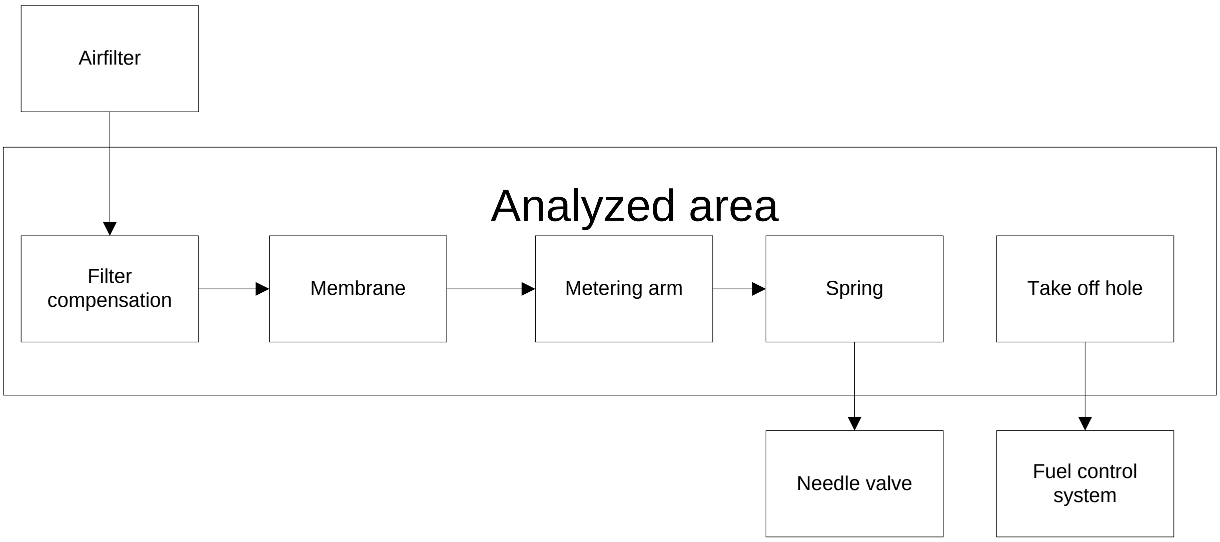
Reverse engineering for metering chamber

Design Organization: Husqvarna AB | **Date: 1/2-2017**

Product Decomposed: Metering chamber on AT11

Description: The metering chamber stores fuel for the fuel control system.

How it works: The metering chamber controls the fuel to the fuel control system through the needle valve in the pump. The function is based on a membrane that pushes a metering arm to open the needle valve and filling the chamber with fuel. As the fuel level is lowered the membrane pushes the metering arm to open the needle valve for filling the metering chamber once again.



Interfaces with other objects:

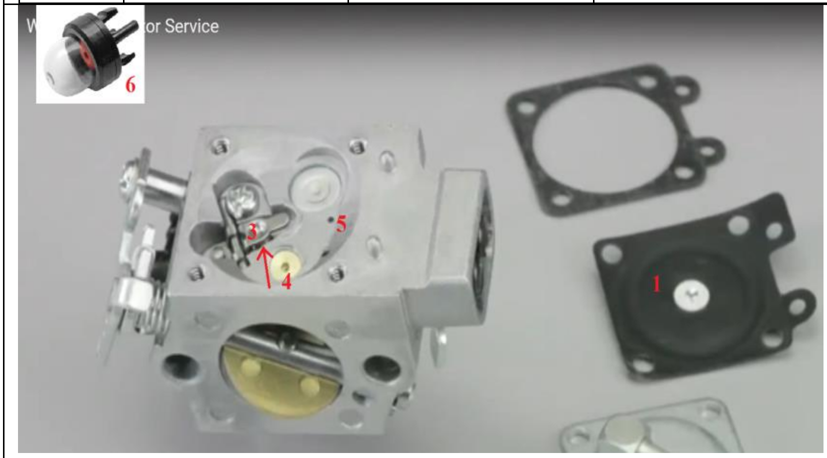
Part #	Part Name	Other object	Energy flow	Information Flow	Material Flow
1	Membrane	Air filter, metering arm	Fuel is extracted by the fuel control system creating a pressure drop forcing the membrane to push the metering arm.	The pressure drop pushes the membrane down on the metering arm opening the needle valve to fill the metering chamber with fuel. Depending on the stiffness of the membrane, height of the metering arm and the spring the needle valve will open differently.	Membrane pushes the metering arm

2	Filter compensation	Air filter, membrane	As the air filter gets clogged, the pressure difference between the outside and inside of the filter increases. This will lead to a lower air supply available for the engine.	When the filter is clogged the engine will run richer due to less air. To prevent this a filter compensation is used, it links the metering chamber membrane to the fuel	As the filter get clogged the metering chamber membrane compensates for the loss of air by reducing the fuel level
3	Metering arm	Spring, membrane	As the membrane pushes down on the metering arm the needle attached to it will open the valve between the pump and metering chamber allowing fuel to be extracted from the needle chamber.	The height of the metering arm will affect the air to fuel ratio in the engine. A lower arm will open later than a higher arm since the membrane needs to move a large distance with a lower arm. A lower arm will result in a lean fuel mixture and a higher arm will result in a more rich fuel mixture	Membrane pushes the metering arm opening the needle vale to fill the metering chamber
4	Spring	Metering arm	To respond to the reacting force of the membrane a spring under the metering arm is used. The spring will close the needle valve when the chamber is filled with fuel and the membrane is pushed upwards.	Depending on the spring-constant the closing and opening of the valve will be affected. A softer spring will give a richer mixture then a harder.	The spring helps the metering arm closing the needle valve.

5	Take off hole	Metering chamber body, Autotune	The takeoff hole is placed in the metering chamber body. The fuel is extracted from the metering chamber by the fuel control system.	The location of the takeoff hole can cause problems if it is in an turbulent area of the metering chamber, since it can harm the delivery to the fuel control system	Fuel is extracted by the fuel control system
6	Primer bulb	Take off hole, Autotune, Fuel tank	To fill the metering chamber with fuel and to extract vapor a primer bulb is used.	The primer bulb extracts fuel or vapor from the metering chamber through the takeoff hole and back to the tank.	The primer bulb is used by the operator

Flow of Energy, information and materials

Part #	Part Name	Interface part	Flow of energy, information, material	Image
1	Membrane	3	NA	NA
2	Filter compensation	1	NA	NA
3	Metering arm	1,3	NA	NA
4	Spring	2,3	NA	NA
5	Take off hole		NA	NA
6	Purge		NA	NA



APPENDIX FOUR

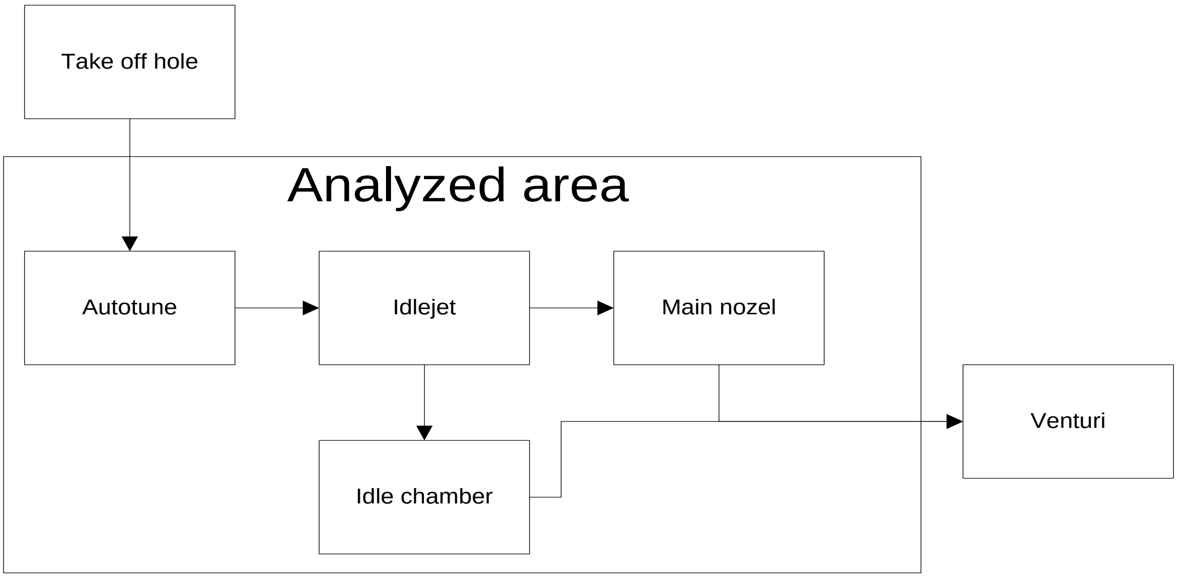
Reverse engineering for fuel control system

Design Organization: Husqvarna AB	**Date: 1/2-2017**

Product Decomposed: Fuel control unit on carburetor AT11

Description: The examined carburetor has an electronic controlled fuel flow called Autotune invented by Husqvarna AB.

How it works: As fuel is extracted from the metering chamber it passes through the Autotune module before going to the idle or main circuit. When the idle circuit is in use the main circuit is closed, when the main circuit is used the idle circuit is closed. Due to the innovation rights of Autotune not all function of it can be exposed.



Interfaces with other objects:

Part #	Part Name	Other object	Energy flow	Information Flow	Material Flow
1	Auto tune	Metering chamber, idle and main circuit	The module is based on a solenoid opening and closing between the metering chamber and the idle and main circuit.	When the engine is running on a lean mixture the valve opens more frequently and if the mixture is to rich the valve close more often to always secure an optimal mixture of fuel and air.	When the engine is running Autotune optimizes the air to fuel ratio of the engine

2	Idle jet (idle circuit)	Autotune, idle jet chamber	The idle jet is opened and closed by a plastic disc controlled by the pressure within the venturi	The pressure drop on the engine side of the throttle plate will open the idle jet, allowing fuel into the idle chamber	Engine is started and throttle plate is in position zero
3	Idle chamber (idle circuit)	Idle jet	A chamber with three different holes one idle hole and two partly throttle holes.	When idling the engine, only fuel from the idle hole will be extracted to the venturi, on partly open throttle the other two holes will help with more fuel.	Fuel is regulated through the partly open throttle and idle holes during idling and partly opened throttle.
4	Main jet	Idle jet, Autotune	The main jet is placed on the air filter side of the carburetor. The jet operates with the same principal as the idle jet with a plastic disc	When the throttle plate is wide open, an over pressure on the engine side will occur and a under pressure on the air filter side of the throttle plate will occur, forcing the disk down and opening the main jet	The throttle is moved from part throttle to wide open throttle.

Flow of Energy, information and materials

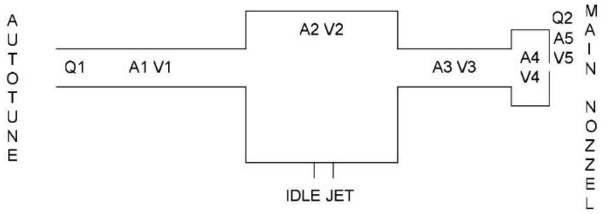
Part #	Part Name	Interface part	Flow of energy, information, material	Image
1	Auto tune	3,4	NA	NA
2	Idle jet	1	NA	NA
3	Idle jet chamber	2	NA	NA
4	Main jet	2,1	NA	NA

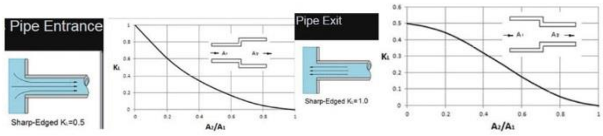
The Mechanical Design Process Designed by Professor David G. Ullman

 Form # 17.0

APPENDIX FIVE

Calculations of reynolds number, major and minor energy losses between autotune and main nozzel





The formulas used for the calculations is gathered from the book a brief introduction to fluid mechanics chapter 8 (Young, Munson, Okisihi, & Huebsch, 2007).

HL major represents the energy losses from the length of the pipe, the two parameters that are deepening is the surface and the length of the pipe.
HL minor represent the energy losses due to changeover in cross-sectional areas within the system. It is not always the cases the HL major is the main contributor to the energy loss.

1.5 mm channel

```
Remove["Global`*"]

pipediameter = 0.015;
A1 = pipediameter^2 * π;
A2 = 0.006 * 0.005;
A3 = pipediameter^2 * π;
A4 = 0.002 * 0.003;
A5 = 0.0007^2 * π;
q = 3.08 * 10^-6;
g = 9.81;


Solve[q == v1 * A1, v1]
{{v1 → 0.00435731}}
```

Page 1

```
V3 = V1 = 0.004357308664204779`
0.00435731
```

$V2 = \frac{A1 * V1}{A2}$

0.102667

```
V1 = V3
0.00435731
```

$V4 = \frac{A3 * V3}{A4}$

0.513333

$V5 = \frac{q}{A5}$

2.0008

Contraction between A1 and A2

$\frac{A2}{A1}$

0.0424413

This will give a K value of 0.98

Contraction between A2 and A3

$\frac{A3}{A2}$

23.5619

Sharp exit K value of 1

Contraction between A3 and A4

$\frac{A4}{A3}$

0.00848826

This will give a K value of 0.98

Contraction between A4 and A5

$\frac{A5}{A4}$

0.256563

This will give a K value of 0.43

Page 2

$HL12 = \frac{0.98 * V1^2}{2 g}$

$HL23 = \frac{1 * V3^2}{2 g}$

$HL34 = \frac{0.98 * V3^2}{2 g}$

$HL45 = \frac{0.43 * V4^2}{2 g}$

9.48339×10^{-7}

9.67693×10^{-7}

9.48339×10^{-7}

0.00577522

```
HLminortot15 = HL12 + HL23 + HL34 + HL45
0.00577808
```

1 mm channel

```
Remove["Global`*"]

pipediameter = 0.01;
A1 = pipediameter^2 * π;
A2 = 0.006 * 0.005;
A3 = pipediameter^2 * π;
A4 = 0.002 * 0.003;
A5 = 0.0007^2 * π;
q = 3.08 * 10^-6;
g = 9.81;

Solve[q == v1 * A1, v1]
{{v1 → 0.00980394}}

V3 = V1 = 0.004357308664204779`
0.00435731
```

$V2 = \frac{A1 * V1}{A2}$

0.0456296

```
V1 = V3
0.00435731
```

Printed by Wolfram Mathematica Student Edition

Page 3

$$V4 = \frac{A3 * V3}{A4}$$

0.228148

$$V5 = \frac{q}{A5}$$

2.0008

Contraction between A1 and A2

$$\frac{A2}{A1}$$

0.095493

This will give a K value of 0.98

Contraction between A2 and A3

$$\frac{A3}{A2}$$

10.472

Sharp exit K value of 1

Contraction between A3 and A4

$$\frac{A4}{A3}$$

0.0190986

This will give a K value of 0.98

Contraction between A4 and A5

$$\frac{A5}{A4}$$

0.256563

This will give a K value of 0.43

Page 4

$$HL12 = \frac{0.99 * V1^2}{2\,g}$$

$$HL23 = \frac{1 * V3^2}{2\,g}$$

$$HL34 = \frac{0.99 * V3^2}{2\,g}$$

$$HL45 = \frac{0.43 * V4^2}{2\,g}$$

9.58016×10^{-7}

9.67693×10^{-7}

9.58016×10^{-7}

0.00114078

HLminortot1 = HL12 + HL23 + HL34 + HL45

0.00114367

HL major

```
Remove["Global`*"]
```

$Q = 3.08 * 10^{-6}$;
$V = 4.35 * 10^{-6}$;
$u = 6 * 10^{-6}$;
$d_{15} = 0.015$;
$d_{10} = 0.01$;
$L = 0.085$;
$g = 9.81$;

$$RE_{15} = \frac{(4 * Q)}{d_{15} * \pi * u}$$

43.5731

$$RE_{10} = \frac{(4 * Q)}{d_{10} * \pi * u}$$

65.3596

$$HLmajor15 = \frac{64}{RE_{15}} * \frac{L}{d_{15}} * \frac{V}{2 * g}$$

$$HLmajor10 = \frac{64}{RE_{10}} * \frac{L}{d_{10}} * \frac{V}{2 * g}$$

1.84535×10^{-6}

1.84535×10^{-6}

Summery of calculations

Reynolds number for 1,5 mm channel is:
43,6
Reynolds number for 1 mm channel is:
65,4
Major energyloss due to change of channelsize is zero.
The energyloss is:
1.84535×10^{-6} Joule
Minor energyloss with 1,5 mm channel is:
0.000233873 Joule
Minor energyloss with 1 mm channel is:
0.0000485151 Joule

Diffrence in energyloss between 1,5 mm and 1 mm

0.005778082403089266` / 0.001143667534153118`

5.05224

Reynolds number side the system

$$Q = A * V$$

$$Reynolds\ number = \frac{fluid\ velocity * pipe\ diameter}{Kinematic\ viscosity}$$

$$A = \pi \frac{D^2}{4}$$

$$Reynolds\ number = \frac{4 * Q}{D * \pi * V_{kinematic\ viscosity}}$$

lowering the RE number although 10% will not be measurable in the terms of engine stability.

Density of fuel	$720 \frac{Kg}{m^3}$
Area	$7{,}07 * 10^{-4}\ m^2$
fluid velocity	$4{,}35 * 10^{-6}\ \frac{m}{s}$
Fuel flow	$3{,}08 * 10^{-6}\ \frac{m^3}{s}$
Kinematic viscosity	$6 * 10^{-6}\ \frac{m^2}{s}$

In[103]:= $Q = 3.08 * 10^{-6};$
$V = 4.35 * 10^{-6};$
$u = 6 * 10^{-6};$
$d_{15} = 0.015;$
$d_{10} = 0.01;$
$L = 0.085;$
$g = 9.81;$

In[110]:= $RE_{15} = \frac{(4 * Q)}{d_{15} * \pi * u}$

Out[110]= 43.5731

In[111]:= $RE_{10} = \frac{(4 * Q)}{d_{10} * \pi * u}$

Out[111]= 65.3596

In[113]:= $HLmajor = \frac{64}{RE} * \frac{L}{d} * \frac{V}{2 * g}$

Out[113]= 1.84535×10^{-6}

APPENDIX SIX

Fuel tank

- Pressure valve
  Under pressure
  Over pressure
- Flow restriction in fuel filter
- Fuel evaporation
- Air sucking

  Carburetor pump

  - Back valve
  - Pump chamber volume
  - Needle chamber volume
  - Needle seat
  - Turbulent flow under needle seat (bleed to fuel hoes)
  - Pressure peak in fuel flow

    Metering chamber

    - Metering arm
    - Metering spring
    - Needle
    - Geometry of chamber
    - Take off hole

      Fuel control system

      - Length of main nozzle
      - Side feed size
      - Size of channel
      - Idle pocket size
      - Remote jet

APPENDIX SEVEN

Manufacturability

The recommended carburetor only need a change of a drill size during the manufacturing process. The remote jet needs two new different milling sizes and two new channels to be manufactured. Furthermore, the remote jet features a lid with a pressure fitting that needs to be done.
Conclusion made is that the when reviewing the two carburetors the recommended one is more simple to produced and there by more cost efficient.

engine performance

When evaluating the acceleration of the engine from idle to full speed there was a difference between the carburetors. The recommended carburetor is around 50 ms faster in acceleration then the remote jet carburetor. On the idle performance the two carburetors preform the same.
risk

There are two major risk for the two carburetors, the remote jet features more channels and lid with pressure fitting.
With more channels the risk of production malfunction is higher, as well as the pressure fitted lid could start to leak.
The major risk with the recommended carburetor is that the smaller channel has not been tried on an carburetor before at Husqvarna. This is the only major risk with recommended the carburetor

Conclusion

The recommended carburetor has a lower cost and less risks of fault during the production and the lifespan off the carburetor. Furthermore, the engine performance of the engine will be increased with a fast acceleration with the recommended carburetor

Alexander Mattsson
076-817 85 33
mattsson_alexander@hotmail.com

HÖGSKOLAN I HALMSTAD

Besöksadress: Kristian IV:s väg 3
Postadress: Box 823, 301 18 Halmstad
Telefon: 035-16 71 00
E-mail: registrator@hh.se
www.hh.se