

Engine Scavenging Tuning for In-Field Product Expectations of a 45cc Stratified Two-Stroke Power Head

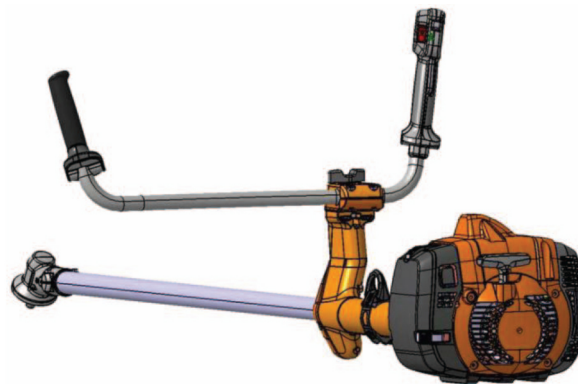
M. Bergman and R. Sundkvist
Husqvarna AB

ABSTRACT

Because of today's new emissions legislation, a new 45cc Husqvarna trimmer/clearing saw power head was needed.

When reducing emissions in a conventional two-stroke engine or a stratified scavenged engine, it is important that the tuning and basic scavenging characteristics of the standard engine are maintained. A dual charge intake system is necessary for the stratified engine but it also creates air/fuel delivery issues compared to a standard two-stroke engine. With increasing trapping efficiency more spent gases mix with the fresh charge, creating less favorable combustion properties and thermal loading on the engine. On top of this the sequential stratified scavenging technology introduces a spatial inhomogeneous mix problem between scavenging fresh air, new mixture and spent gases. This all adds sensitivity to long term stability due to deposits of carbon both in combustion chamber and exhaust duct, resulting in a change in engine parameters due to aging.

There is of course a limit of what can be done in aspects of fuel trapping versus product performance with a simple two-stroke power head design when relying on a standard type mechanical carburettor fuel system. When optimizing the engine aspiration by tuning of intake and scavenging ducts geometry in dependence with static piston port timing.



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INTRODUCTION

In this paper the focus will be on the optimization necessary to arrive at an engine design that not only meets the emission legislation but also performs as expected by the customer of the product. Idling, acceleration etc. are all dependent on characteristic of the engine behaviour in

varying surroundings. First a one dimensional model simulation is presented, followed by results from dyno testing. Then we will present the shortcomings found and solutions taken to deal with them.

The method for emission reduction for this particular engine is the sequentially stratified scavenged engine technology, which is characterized by the principle that burnt

gas is first scavenged by pure air, followed by the air/fuel mixture. The pure air is introduced into the upper part of the scavenging ducts through a piston port. To take full advantage of the stratified scavenged principle, the scavenging ducts have to be designed in a way, so that they can accommodate all the pure air needed to reduce the scavenging losses.

The main problem with the small two-stroke engine of today is hydrocarbon emissions, which are caused by the scavenging losses. With ever more stringent emission regulations, put forward mainly by EPA and CARB, it becomes evident that the two-stroke engine will not survive as a simple and cost effective power source in the future unless some new techniques are introduced, or major improvements are made to the existing ones.

One of the many [1] different techniques that have been suggested to reduce the scavenging losses is sequentially stratified scavenging. To be able to take full advantage of this design, it is important to understand the differences this introduces to the standard two-stroke engine.

THE SEQUENTIALLY STRATIFIED SCAVENGED ENGINE PRINCIPLE

In a stratified scavenged engine, the scavenging process is divided in two parts, one that consists of pure air, and the other, which is the air/fuel mixture. Much research work has been carried out in this area, some highlights can be found in the reference section [2, 3, 4, 5, 6, 7, 10 and 11].

The stratified scavenging can be done in two ways, either parallel or sequential stratification. In the parallel system, the cylinder is then scavenged by air and air/fuel mixture at the same time, but through separated systems. The pure air is preferably delivered to the cylinder through the scavenging ducts closest to the exhaust port.

In the sequential stratification system, the cylinder is then first scavenged by pure air followed by the air/fuel mixture. The work described in this paper focuses on this principle, but much of the theories and principles would be helpful when designing a parallel stratified scavenged engine as well.

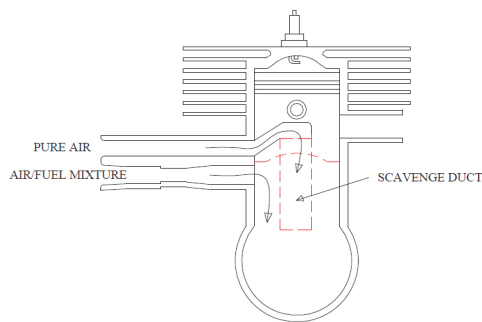


Figure 1. Sequentially stratified scavenged engine during intake stroke

In Figure 1 a simple sketch of a sequentially stratified scavenged engine can be seen. During the intake stroke air is delivered at the upper part of the scavenging ducts, either through a port controlled by the piston as in this case, or a reed valve. At the same time air/fuel mixture is delivered to the crankcase through the ordinary intake port. This port can also be either a reed valve port, or a piston port. This causes the scavenging ducts to be filled with air, and the crankcase to be filled with rich air/fuel mixture.

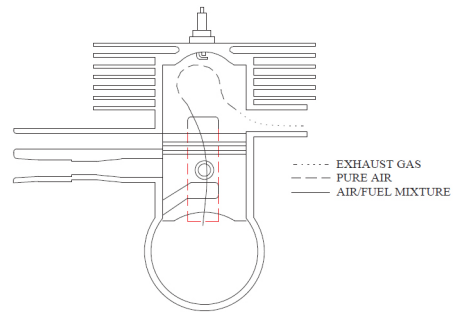


Figure 2. Sequentially stratified scavenged engine during scavenging

During scavenging, the flow out of the exhaust port is intended to be in the same sequence as the inflow through the scavenging ports. Namely, after the exhaust gases follow the pure air that was trapped in the scavenging ducts, and finally the air/fuel mixture. Since the first part of the scavenging losses is only air, the thought is that the loss of fuel will be substantially lower.

Stratified scavenging introduces many new issues in the development process of the engine. Air/fuel ratio control becomes more complicated. The relationship between the amount of air that goes through the pure air system versus amount of air through the carburettor is another important design factor that does not exist with the standard two stroke engine.

In this paper we will discuss the development of a 45 cc trimmer and clearing saw engine. This engine is a sequential stratified piston ported two stroke engine as described above.

ENGINE DESIGN

As outlined in previous work [6, 7] there are some important aspects to consider when designing a stratified engine.

In this case we chose to start to build a prototype engine based on an existing chain saw known to have good scavenging qualities, hence meets the EPA regulations. The H445 Husqvarna chainsaw. See Figure 3.



Figure 3. Husqvarna H445 chainsaw

To understand what to alter to reach engine performance targets, a 1D simulation model in the engine simulation software VIRTUAL 2-STROKE from OPTIMUM Power Technology was built up, see Figure 4 and 5.

The task was to build one engine with two different engine characteristics, to accomplish customer acceptance in the different applications. To keep cost down it is important to achieve this with minimal alteration between the hardware of the engines.

The table below describes the difference in specification.

Table 1. Specification for 45 cc engines

Engine	Clearing saw	Trimmer saw
Power	2.1 kW@9500 rpm	2.0 kW@8000 rpm
Torque	Min 2.4 Nm	Min 2.6 Nm

By simulation we could estimate the possible differences between the engines by change of geometries like scavenging duct lengths, port timing, intake system etc.

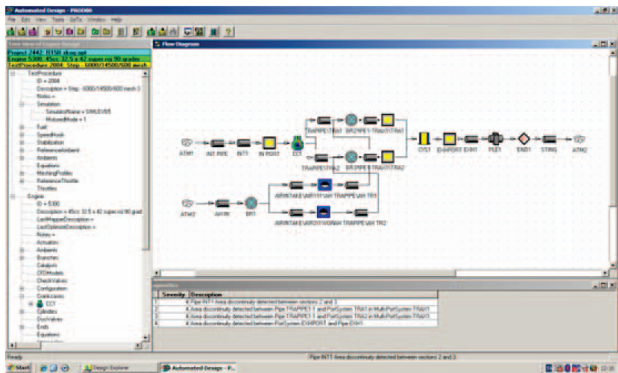


Figure 4. Simulation model in VIRTUAL 2-STROKE from OPTIMUM Power Technology

The model was based and calibrated on the stratified chainsaw engine H445 and then altered to reach the requirements of the power head for the trimmer and clearing saw product. No air filter or intake box was included in the 1D model. Instead the restrictions where taken into account when calibrating the initial model to dynodata.

In fig 5 a more detailed picture of the actual model of the intake and scavenging system is shown. The yellow squares represent the intake port and scavenging ports. Piston port

valves for control of pure air scavenging “AH” are shown as blue squares. The intake and scavenging ducts to be optimized for length and volume are clearly marked for clarity.

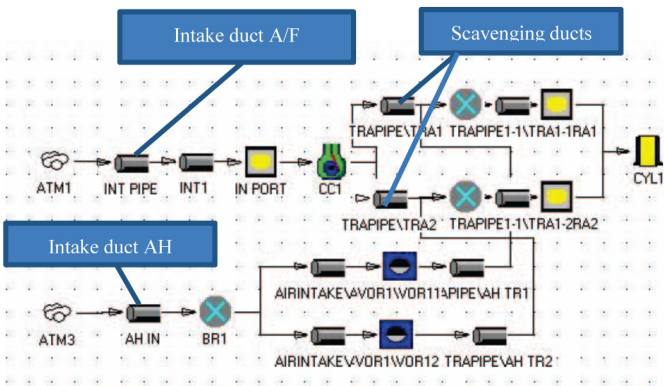


Figure 5. Detailed part view of model in VIRTUAL 2-STROKE adjusted ducts marked in model.

Basic engine data for engine simulation see table 2.

Table 2. Specification for 45 cc engine

Engine	Trimmer	Clearing saw
Bore [mm]	42	42
Stroke [mm]	33	33
Connecting rod length [mm]	58.5	58.5
Trapped compression ratio	7.5	7.5
Intake A/F dur [CAD]	154	154
Intake Air dur [CAD]	145	145
Scavenging port dur [CAD]	133	133
Exhaust port dur [CAD]	136	136
Scavenging duct length [mm]	130	110

OUTCOME OF SIMULATION

It was stipulated that as much as possible the design should be kept the same between the two different engines. After several simulation runs it was decided that the difference between the engines should be enough by changing the effective length of the scavenging ducts. The cylinder should be the same for both versions of the power head. So the solution was to make a crankcase with interchangeable inserts for altering the scavenging duct length.

In figure 6 it can be seen that the difference in scavenging duct length fulfils the requirement of the different engine

characteristics. Max torque is shifted down in the speed range for the trimmer engine about 10 rps app 600 rpm and the levels of torque are close to the specification of the engines. 2.6 Nm for the trimmer engine and 2.4 Nm for the clearing saw.

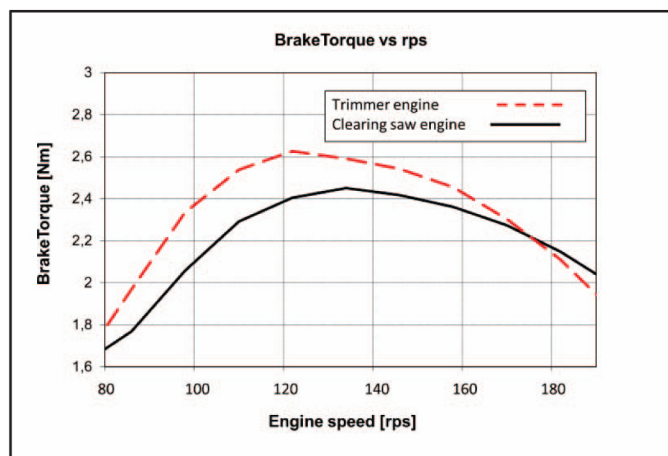


Figure 6. Simulation output for different scavenging duct lengths 110mm versus 130mm.

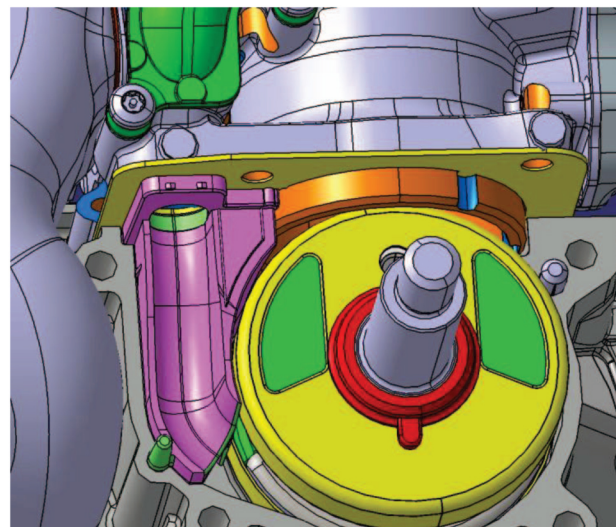


Figure 8. 3D model of mounted trimmer crank case insert with 130 mm duct length.

FIRST PROTOTYPE ENGINE RUN



Figure 7. Crank case inserts for different scavenging duct lengths 110mm versus 130mm.

Based on the data output of the simulation a prototype engine was built. To be able to compare the different

scavenging length effect on the same engine set up, the crankcase was equipped with inserts that was interchangeable, see [fig 7](#) and [fig 8](#).

When some minor deviation between prototype parts and design where sorted out the power output of the engine was close to predicted. See [fig 9](#).

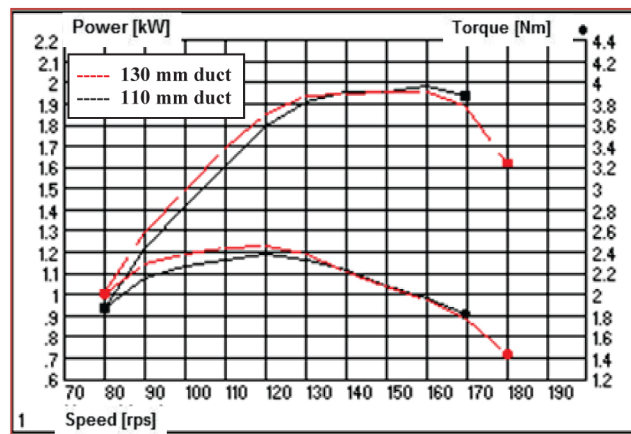


Figure 9. Prototype run power[kW] and torque[Nm] for different scavenging duct lengths 110mm versus 130mm.

It was evident that the low end torque was suffering from a lean A/F situation, see [fig 10](#). This made the engine hesitate during acceleration and fuel wetting of the air filter indicated fuel standoff due to reversion in the intake system.

This is addressed in the section covering intake tuning, optimization of the system by changing length and volumes.

Another issue was erratic combustion, especially with the longer scavenging duct inserts. At high speed or during lean