# A Computer Simulation of KS 90 Stirling Engine

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*Abstract* – **This paper presents a computer simulation in Ringbom Stirling Engine Simulator software by JLB Enterprises and the operating characteristics of Kontax KS 90 Stirling engine.**

*Index Terms* – **Stirling engine, Ringbom**

## I. INTRODUCTION

On 27 September 1816, Church of Scotland minister Robert Stirling applied for a patent for his economiser in Edinburgh, Scotland. The device was in the form of an inverted beam engine, and incorporated the characteristic phase shift between the displacer and piston that we see in all Stirling Engines today. The engine also featured the cyclic heating and cooling of the internal gas by means of an external heat source, but the device was not yet known as a Stirling Engine.

Stirling engines are unique among heat engines because they have a very high theoretical Carnot efficiency, in fact it is almost equal to their theoretical maximum Carnot efficiency. Stirling engines are powered by the expansion (heating) and contraction (cooling) of gas. The fixed amount of gas inside a Stirling engine is transferred back and forth between a hot end and a cold end, which cyclically expands and contracts the gas. [1]

Robert Stirling continued to work on his engines throughout his life. In the 1820's he was joined by his younger brother James, whose major contribution was to suggest pressurizing the internal gas to increase the power output. Further improved design patents were applied for in 1827 and 1840.

Professor Ivo Kolin Early in 1983, Professor Ivo Kolin of the University of Zagreb, Croatia, demonstrated the very first low temperature differential Stirling engine to an amazed audience. This engine ran on a temperature difference of 100°C, which at the time was an astonishingly low figure. The demonstrated engine ran for a long time as the temperature differential lowered, eventually stopping when the difference dropped below 20°C.

This feat was all the more remarkable when you consider the engine was constructed entirely with hand tools. The engine had no power piston and cylinder, instead relying on a rubber diaphragm to transmit the power from the square main chamber. A feature of this engine was the “slip-link”, a device for imparting an intermittent motion to the displacer inside the main chamber. At the low speed that this engine ran at, a dwell at each end of the displacer stroke was very beneficial.

During the late 1980's and the early 1990's Professor Senft of the University of Wisconsin took up the idea of low temperature differential Stirling engines. The first models he produced were Ringbom engines, where there is no direct connection between the flywheel and the displacer, the Ringbom engine is reliant on the changing pressure inside the main chamber to move the displacer back and forth. Professor Senft, working closely with Professor Kolin, continued working with Stirling engines, working out many of the design solutions that are used today in low temperature differential Stirling engines. [2]

In 1992 Professor Senft was asked to design and build a low temperature differential engine for NASA. This engine, called the N-92, was optimised for hand held operation, with a temperature difference as low as 6°C enough to power it. Professor Senft continues to work with Stirling Engines, and has written several books detailing the history and manufacture of Stirling engines.

The KS range of low temperature differential Stirling engines was designed and developed in England in 2002, and has been in continual production ever since. Kontax use modern production machinery to manufacture most of the parts in-house, which allows for very strict quality control.

With the recent ratification of the Kyoto Protocol by 141 countries, Stirling Engines would seem perfectly placed to take up the challenge presented by an energy conscious world. [6]

## II. HOW KONTAX KS 90 STIRLING ENGINE WORKS

All Stirling engines are powered by a difference in temperature. In this low temperature engine this difference is normally achieved by warming the bottom plate to above room temperature and allowing the top plate to stay at room temperature.

In operation the engine cyclically heats and cools the air inside. This process is shown in the simplified cut-away diagrams below (it helps to remember that the large blue displacer disk just moves the air from top to bottom and back again, and it is the small black piston that actually drives the flywheel).

With the large blue displacer disk at the top, all the air inside is at the bottom, where it is heated by the warm plate (Fig. 1). As it warms, it expands, pushing the small black piston upwards, and driving the flywheel around.

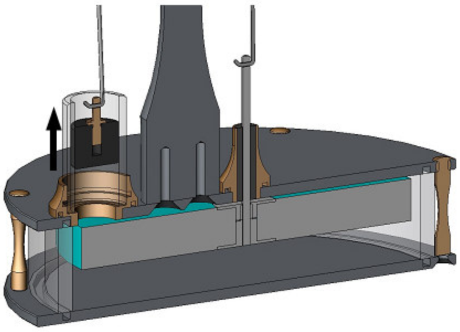

Fig. 1 Displacer disk at the top [reproduced according to 7]

As the flywheel turns, the large blue displacer disk is moved to the bottom of the chamber. With the displacer at the bottom, all the air is at the top, where it is cooled by the cold plate. (Fig. 2) As it cools, it contracts, which has the effect of pulling the small black piston downwards, and driving the flywheel around some more and so the cycle continues.

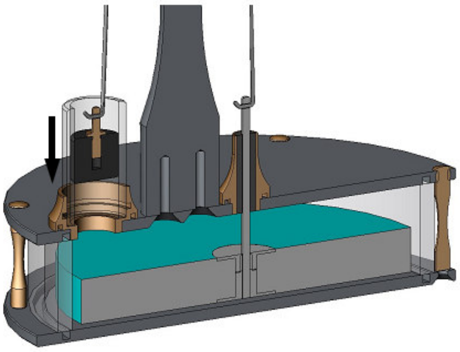

Fig. 2 Displacer disk at the bottom [reproduced according to 7]

With the bottom plate being warmer than the top plate, the engine will spin in a clockwise direction.

But, if you reverse the heat flow and chill the bottom plate then the engine will spin in an anti-clockwise direction.

It doesn't really matter to the engine which of the two plates is the warmer, just so long as one plate is warmer.

The engine is not self-starting; you will need to give the flywheel a little spin to get it going. After the engine has been on your heat source for half a minute to a minute, gently spin the wheel and your engine should carry on running.

Fig. 3 Kontax KS 90 Stirling engine [reproduced according to 9]

All Stirling engines are fully reversible. In the Kontax Low Temperature range this means that instead of warming the bottom plate and cooling the top plate to get clockwise rotation, you can cool the bottom plate and warm the top plate to get anti-clockwise rotation.[3]

The simplest way to get forwards (clockwise) rotation is to hold the engine in the palm of your hand, allow the bottom plate to warm up to the temperature of your hand and gently spin the flywheel clockwise. If your hand is warm enough (and the ambient room temperature cool enough) your engine should continue to run under its own power (as long as you keep it on your hand). If you have a very cold hand and the ambient room temperature is very warm there might not be enough temperature difference between the top and bottom plates for the engine to run.[10]

The simplest way to get backwards (anti-clockwise) rotation is to place the engine over a bowl or saucer of ice, allow the bottom plate to be cooled to below room temperature and gently spin the flywheel anti-clockwise. As with conventional hand running your engine should continue to run under its own power, for as long as the ice takes to melt and warm up to room temperature. Ice running is very reliable, because there is usually a greater temperature difference between ice and the ambient room temperature than between hand heat and ambient room temperature.[4]

The Kontax Low Temperature Differential Stirling Engine is an excellent demonstration of a heat engine, showing with one spin of the flywheel a clean and simple way of converting thermal energy into motion. This engine will operate from many heat sources, including hot water, computer monitor, TV and the human hand**.** As long as there is a small difference in temperature between the upper and lower plates this engine will run. [7]

This engine has been meticulously engineered. As any Stirling Engine enthusiast knows, friction is your enemy in LTD models. With this in mind, all potential sources of friction in this engine have been eliminated. Another common problem with LTD Stirling is heat transfer between the plates. Again, all possible routes for heat to transfer directly between the plates have been eliminated.

Based on the pioneering work done by Dr. Senft at the University of Wisconsin, this model has been engineered in England, manufactured in England using hi-tech CNC equipment, and is sold from England.

A large number of schools and universities have bought our engines for educational use, the transparent chamber and cylinder make it very easy to explain the Stirling cycle to students. Many of our engines have been kept running for years on top of coffee machines, computers, fax machines, etc. in shops, kitchens and offices all over the world. Many customers take great delight in running our engines on a bowl of ice or snow, where the engine happily runs, but backwards.

The features of this engine are:

- Low-profile heat insulating chamber pillars, giving good surface contact with heat source;
- Aluminium main pillar, hub and spokes;
- All airtight seals are made with high strength precision screw threads and nitrile O rings;
- Both connecting rods are positively located using low friction PET and stainless screws;
- Micron precision Borosilicate glass cylinder and Graphite power piston, the best combination;
- Ultra low friction demagnetised and degreased bearings, no lubrication required;
- Fully CNC machined, ensuring crisp, clean tidy edges all over;
- Engine parts ultrasonically cleaned before hand assembly;
- Precision engineered.[4]

The major dimensions of the Kontax KS 90 Stirling engines are:

- Base plates – 92 mm diameter, 2 mm thick;
- Flywheel – 82 mm diameter, 4mm thick;
- Power piston - 9.5 mm tube diameter;
- Displacer – 70 mm diameter, 8mm thick;
- Overall height – 120 mm.

## III. A COMPUTER SIMULATION OF KS 90 STIRLING ENGINE

For computer simulation and examining the operating characteristics of the Kontax KS 90 Stirling engine, the software Ringbom Stirling Engine Simulator by JLB Enterprises was used.

Some assumptions were made:

1) The bottom of the Displacer Cylinder is at the Hot temperature, and the top of the Displacer Cylinder is at the Cold temperature.

2) The temperature of the walls of the Displacer Cylinder varies linearly from hot on the bottom to cold on the top.

3) The temperature of the air in the Displacer Cylinder is the average of all of the wall temperatures.

4) The gas under the Displacer (the hot gas) is uniformly at the average exposed wall temperature.

5) The gas above the Displacer (the cold gas and the piston gas) is uniformly at the average exposed wall temperature.

6) The pressures in all parts of the Displacer, and the lower part of the piston, are all the same.

7) The pressure in the Displacer Cylinder is at ambient pressure at the time-averaged-mean of the internal engine pressure. This corresponds to the fact that most engines are not perfectly sealed, and will reach this pressure over time.

8) All physical analysis is "static"; the weights and moment of the Displacer and Piston are ignored.

9) The Piston is connected to a flywheel, but is not shown; the Piston and Displacer are not connected.

10) All of the calculations are unit less.

11) Pistons are considered to be weightless.

12) The Displacer moves up and down when the internal engine pressure rises above or falls below some pre-computed pressure values. Thus, the weight of the displacer is ignored, as is the cross-section of the displacer piston. This severely limits the utility of this simulation, although it still can be used to demonstrate many interesting aspects of the Ringbom's behavior.[5]

The output values can be seen in the graphs, and in the vertical stack of numbers in the upper right:

1) Displacer Position and Piston Position show the current locations; zero is at the bottom.

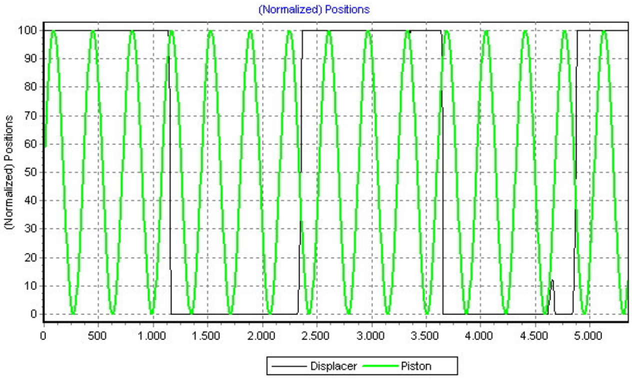

Fig. 4 Displacer and piston position

2) Pressure is current, and not normalized. A "+" indicates current pressure is above ambient; a "-" indicates it is below ambient. This value is important, since this tells whether the internal gas is trying to press the pistons "out" or "in".

3) Volume is normalized to 100 % of possible volume (piston all the way out, Displacer all the way up).

4) Hot N and Cold N is the percent of the gas which is in the hot and cold parts of the Displacer cylinder.

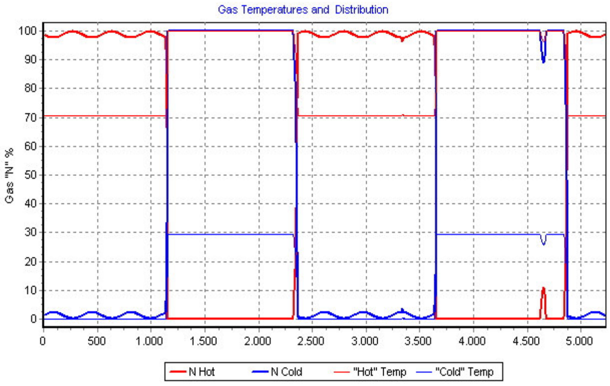

Fig. 5 Gas temperatures and distribution

5) Mean Pressure is that which is equal to ambient.

6) Volume Ratio is the ratio of the Displacer swept volume to the Piston swept volume. Large values are to be expected for low temperature (high efficiency) engines; values near 2 are to be expected for high temperature engines.

7) Temperature Ratio is the ratio of the Hot vs Cold temperatures, expressed in Kelvin (absolute temperature). This is the same as the expected gas volume ratio when moved from cold to hot. Low temperature engines can have ratios around 0.01; high efficiency engines often have ratios near 1.

8) The second Temperature Ratio is the same as above, only this time we take into account the fact that the walls of the Displacer Cylinder are not perfect insulators. As the Displacer gets shorter, more and more of the Displacer Cylinder walls are exposed, and the effective temperature ratio is reduced. This is that reduced ratio.

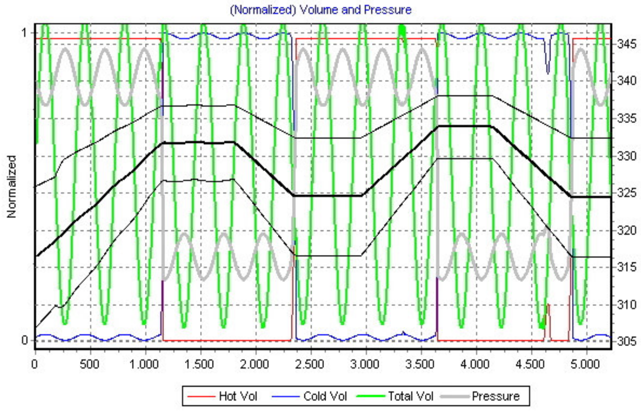

Fig. 6 (Normalized) Volume and pressure

9) Theoretical Piston Throw is our best guess at how far the Piston should travel. This value is computed by setting the engine to the design temperature with the Displacer and Piston at the bottom (zero) location, and then pulling the Displacer up (with the Displacer not connected to the Piston). The resulting gas expansion should push the Piston

up the indicated distance. The two values correspond to the two different Temperature Ratios.

10) The dependence between the pressure and volume is presented below (Fig. 7) in the PV diagram:

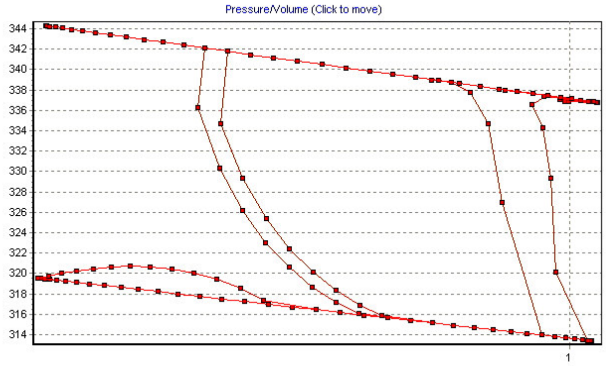

Fig. 7 PV diagram

11) Net Work is the total of all the work the piston does (Fig. 8). This is the most important value of all: if this value is positive, the engine will continue to run and do work; if this value is negative, there will not be enough power to keep the engine running. It represents whether the engine delivers net energy to the flywheel, or not.

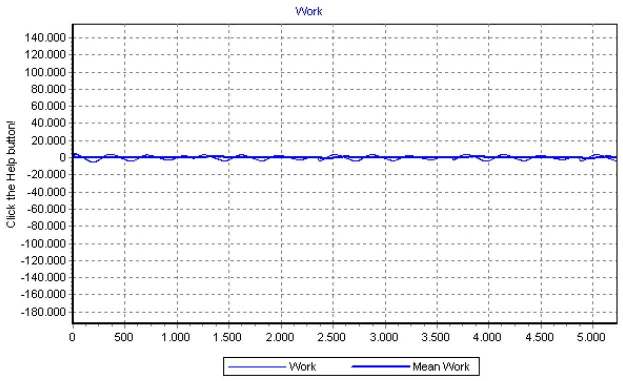

Fig. 8 Work diagram

## IV. CONCLUSION

- These engines can use any type of energy, not just solar;
- They can use light cylinders;
- They are silent in use;
- Low pollution;
- Less lubricate and larger functioning time;[8]
- The acting mechanisms are simple (no valve needed);
- No danger of explosion;
- They start easy and they work better on cold temperature;

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