23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

NUMERICAL ANALYSIS AND MODELING OF A THREE STROKE IC ENGINE

Vinicius Bonfochi Vinhaes
Centro Universitario da FEI – Av. Humberto de Alencar Castelo Branco 3972, São Bernardo do Campo, 09850-901
vinicius.vinhaes@gmail.com

Claudio Barberato
Centro Universitario da FEI – Av. Humberto de Alencar Castelo Branco 3972, São Bernardo do Campo, 09850-901
claudio.barberato@gmail.com

Abstract.
A three-stroke internal combustion engine is a proposed engine which completes a complete combustion cycle of exhaust, intake, compression and expansion within a single revolution of a crankshaft. In this engine two pistons are housed in a single cylinder. The first piston is a common piston-connecting rod-crankshaft assembly, and it is responsible for the compression and expansion parts of the cycle. The second piston is a much lighter assembly and it is driven by means of rocker arm which follows a cardioids path milled in the crankshaft. The second piston is responsible for the exhaust and intake part of the cycle. This paper presents key parts of a three stroke engine modeled through Computer Aided Design (CAD) and studied numerically using Computer Aided Engineering (CAE). The purpose of the analyses is to assist the building of a prototype of such engine which, if shown feasible, will present several benefits when compared to the conventional four stroke engines, such as better power to weight ratio and higher fuel efficiency. A commercial computer aided design software was applied for building the models and a commercial computer aided engineering software was applied to the numerical analysis. Only the parts of this engine which differentiate them from a conventional four stroke engine, namely the connecting rod and the rocker arm, were studied. The two moments during the cycle which have the highest stresses were selected for each component, respectively, the maximum pressure inside the cylinder and the maximum acceleration for lighter piston. For simplicity, both scenarios were studied as static cases, because they lessen the inherited difficulties of designing and simulating complex energy systems such as an engine. The numerical analyses for both connecting rod and rocker arm show that the maximum deformations for the applied loads were within expected. The results show that the proposed components can cope with the maximum stresses found in a conventional engine and therefore the next stages of the development of a three stroke engine can be pursued

Keywords: *Engine, 3D Modeling, Structural Analysis*

1. INTRODUCTION

A regular IC engine piston is designed to withhold high surface pressures for the compression and expansion strokes in the Otto cycle, while is also used during lower pressures strokes such as exhaustion and intake. Very little work is involved in this two latter strokes, also, to reach a power stroke (expansion stroke) the crankshaft must complete two full revolutions. (Pulkrabek, 2004).

The Three Stroke Engine (TSE) is assembled by adding a smaller piston inside the combustion chamber with the regular piston. This smaller piston is intended to work during exhaustion and intake strokes, which no high stresses are present within the cylinder. However during the power stroke both pistons are to be touching each other, therefore the higher stresses of the combustion and expansion are held by the regular IC engine piston. Figure 1 shows the Three Stroke Engine cycle and how it works.

Where TDC is the Top Dead Center, when the piston reaches its higher position within the cylinder and BDC is the Bottom Dead Center, when the piston reaches the lower position during its movement within the cylinder. TDC represents the zero degrees of the crankshaft's revolution and the BDC represents 180 degrees.

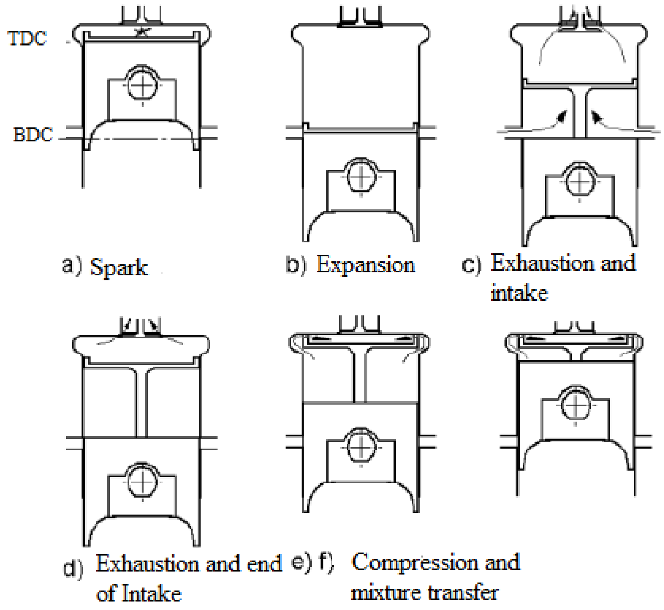

Figure 1. The Three Stroke Cycle

The three stroke cycle provides the power stroke at each revolution of the crankshaft, as seen on Fig.1, expansion and intake are performed at the same time, similarly to the two stroke cycle, but the exhaust gases do not mix with the newly intake air and fuel.

This approach brings several advantages over the four stroke cycle, the engine will be lighter, since each full revolution of the crankshaft produces a power stroke, and therefore the number of pistons could be reduced by half. The engine will naturally run the Atkinson cycle, where the expansion ration is bigger than the compression ratio, resulting in a higher energetic efficiency. The intake is on the cylinder's side openings providing less restriction to the air flow, although some lubricant will be among the new air fuel mixture. The transferring of the air fuel mixture to the upper part of the assembly will grant a better swirl and homogenous mixture. The engine vibration is slightly reduced by the smaller piston's movement.

Figure 2 is a comparison between the P-V diagrams of several four stroke cycles.

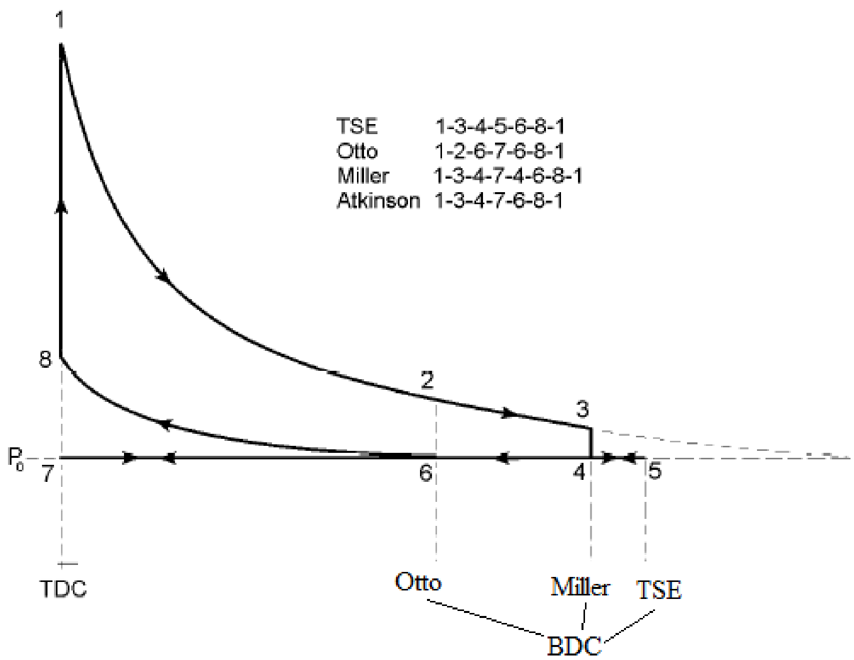

Figure 2. P-V diagrams of four stroke cycles

The objective of this research is to present the key parts of the Three Stroke Engine modeled on a Computer Aided Design (CAD) software and their numerically studies using Computer Aided Engineering (CAE).

2. THE THREE STROKE ENGINE

2.1 Thermodinamical analysis and comparisson of the Three Stroke Engine cycle.

Pulkrabek (2004) and Garcia (1998) works presents the equations to compute the analytical approach to develop the calculation of the performance values shown on Tab.1. This was made to show a comparison on the Three Stroke Engine vs the Four Stroke Engine.

Table 1. Engine dimensions and thermodynamic calculation for comparison of the Otto cyle and TSE Cycle
All Units in SI

	Otto	**TSE**
Piston Diameter [m]	0,0800	0,0800
Strokes 1 and 2 [m]	0,0800	0,0480
Strokes 3 and 4 [m]	0,0800	0,0780
Revolutions per cycle	2	1
Number of cylinders	4	2
Compression ratio	10,0	10,0
Expansion ratio	10,0	13,5
Combustion chamber height [m]	0,0089	0,0046
Combustion chamber volume [m^3]	0,0000447	0,0000313
Fuel passage height [m]		0,0090000
Fuel passage volume [m]		0,0000080
Intake volume [m^3]	0,0004021	0,0002413
Expansion volume [m^3]	0,0004021	0,0003921
Total volume [Liters]	1,6	1,0
Exhaust Gas % intake	0,04	0,04

Constants	
R [kJ . kg^{-1} . K^{-1}]	0,2870
k	13,500
Ethanol	29700
QHV Brazil [kJ . kg^{-1}]	41380
QHV USA [kJ . kg^{-1}]	44300
nc	1
Cv [kJ . kg^{-1} . K^{-1}]	0,821
Cp [kJ . kg^{-1} . K^{-1}]	1,0

1st Stroke (Intake)		
Gas mass [kg]	0,0004675	0,0002852
Air mass [kg]	0,0004208	0,0002567
Fuel mass [kg]	0,0000281	0,0000171
Exhaust mass [kg]	0,0000187	0,0000114
T1 [Celsius]	60	60
T1 [Kelvin]	333	333
V1 [m^3]	0,0004468	0,0002726
P1 [kPa]	100	100

2nd Stroke (Compression)		
T2 [Celsius]	472	437
T2 [Kelvin]	745	710
V2 [m^3]	0,0000447	0,0000313
P2 [kPa]	2239	1859

3rd Stroke (Expansion)		
Qin [kJ]	1,161	0,708
T3 [Celsius]	3497	3462
T3 [Kelvin]	3770	3735
V3 [m^3]	0,0000447	0,0000313
P3 [kPa]	11320	9773

4th Stroke (Exhaustion)		
T4 [Celsius]	1411	1227
T4 [Kelvin]	1684	1500
V4 [m^3]	0,0004468	0,0004233
P4 [kPa]	506	290

The calculations for cycle work and efficiency are shown on Tab. 2.

Table 2. Engines comparison for net-work and efficiency
All Units in SI

Work		
	Otto	TSE
W_{1-2} [kJ]	-0,15813	-0,08826
W_{3-4} [kJ]	0,79960	0,52244
Wnet [kJ]	0,64147	0,43418
Efficiency	0,553	0,613
Improvement		1,11

The analytical approach showed an improvement of 11% on the efficiency of the TSE when compared to the Otto cycle. This verifies that this engine is more efficient numerically, therefore the design models of the key parts can be presented and studied using numerical analysis.

2.2 Computer aided design models

The visualization of a three dimensional model brings easier comprehension of a part once designed when compared to at 2 D model. The designer can manipulate the developed part among assemblies, taking measures and correcting it if necessary. This method is highly used nowadays, especially on complexes elements such as an engine piston. (Samuel, 2004).

By the use of a commercially available CAD software the key parts of the Three Stroke Engine were designed. These parts are the regular piston, the smaller piston, the regular engine rod, part of the crankshaft with a cam to move the base where the smaller piston will be connected.

Also, one important characteristic of an Internal Combustion Engine assembled with crankshaft, connecting rod and piston is the ease to move these parts and how they interact with one another, transforming a reciprocal movement to a rotational movement. (Pulkrabek, 2004).

To prevent the difficulty of designing an all new connecting rod, piston and crankshaft, these parts were merely designed by using already existing parts available in the market.

Figure 3 shows the design of how the Three Stroke engine should look like.

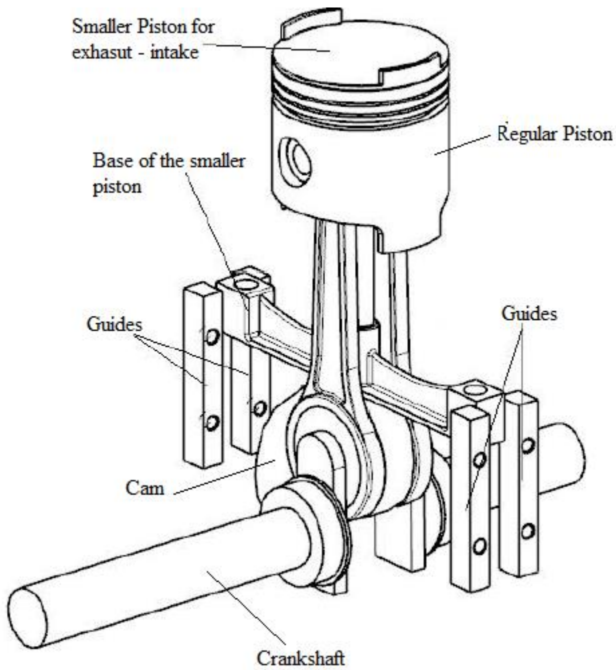

Figure 3. The Three Stroke Engine

The Smaller Piston connects with its base by a rod going through a role that is centered on the Regular Piston, this brings up one of its disadvantage regarding sealing. This sealing is studied on future research work, the present work is intended to validate the stresses that the smaller piston and its structures will have to bare while the engine is running.

Figure 4 is the same assembly with a section view to understand how the smaller piston goes through the regular and connects with its base.

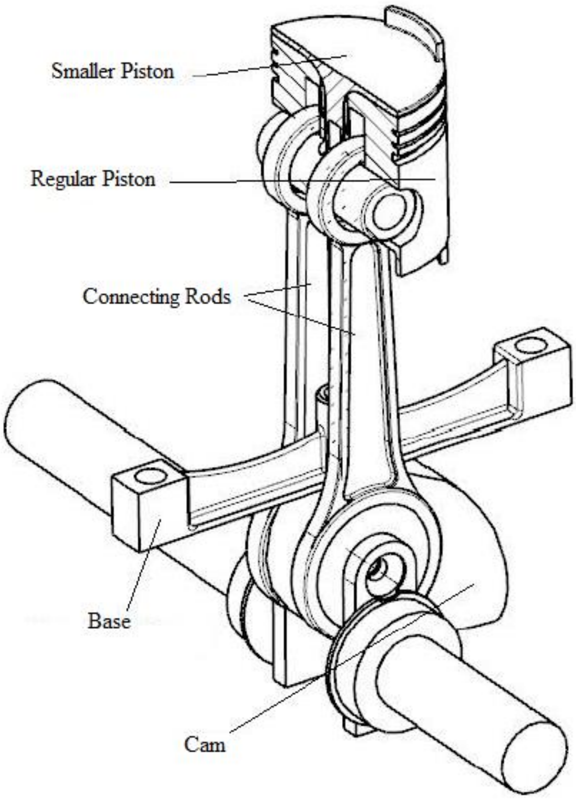

Figure 4. The Three Stroke Engine section view

The view on Fig. 4 shows the use of two connecting rods to connect the regular piston to the crankshaft, this solution was used so the Smaller Piston could go through the middle of the assembly. These connecting rods follow a similar design as the available on current market, however they have a smaller thickness that has also to be verified using numerical analysis. Following on Fig. 5 there are the parts that composes the entire assembly showed before.

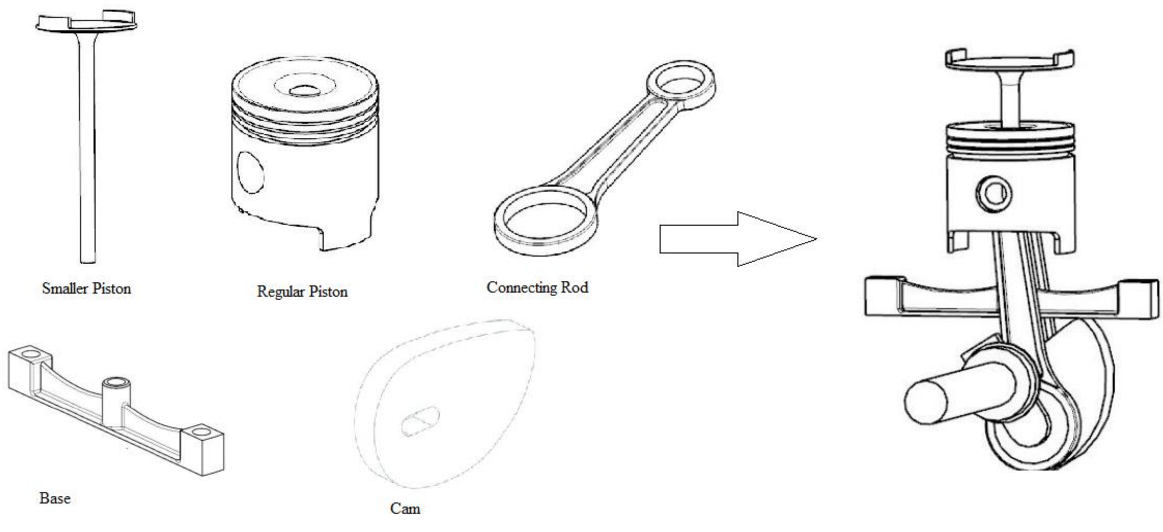

Figure 5. Key parts of the TSE

2.3 Structural analysis with computer aided engineering

Table 3 brings the materials that were assigned to each part of the assembly. The materials were selected based on the materials that are currently used on regular engines, this was just an approximation to verify its behavior on a first stress analysis.

Table 3. Material Selection and Characteristics
Source: Materials web database (2011)

Part	Material			
Smaller Piston Base	Aluminum A4032 T6			
Connecting Rods	Steel			
Cam	Aluminum A4032 T6			
Guides	Aluminum A4032 T6			
Regular Piston	Aluminum A4032 T6			
Smaller Piston	Aluminum A4032 T6			
Crankshaft	Steel			
Material`s Characteristics				
Material	**Density**	**Young`s Modulus**	**Poisson**	**Maximum Elastic Stress**
Aluminum A4032 T6	2680 kg/m³	76.60 GPa	0.34	317 MPa
Steel	7850 kg/m³	200 GPa	0.3	240 MPa

Several numerical analysis were made on the TSE model assembly, but the most relevant for this paper is the one that represents the instant of time in which the engine reaches its peak pressure, around 20 degrees after the Top Dead Center (11.320 MPa – according to the calculation shown o Tab. 1). The peak pressure value adopted for the analysis was the value that a regular Otto's engine reaches. The results are shown on Fig. 6. The analysis were all made considering the pressure on that instant of time, therefore, a static analysis could be used. This would ease the difficulty on the analysis model reducing the computational time and will not compromise the validation of the results.

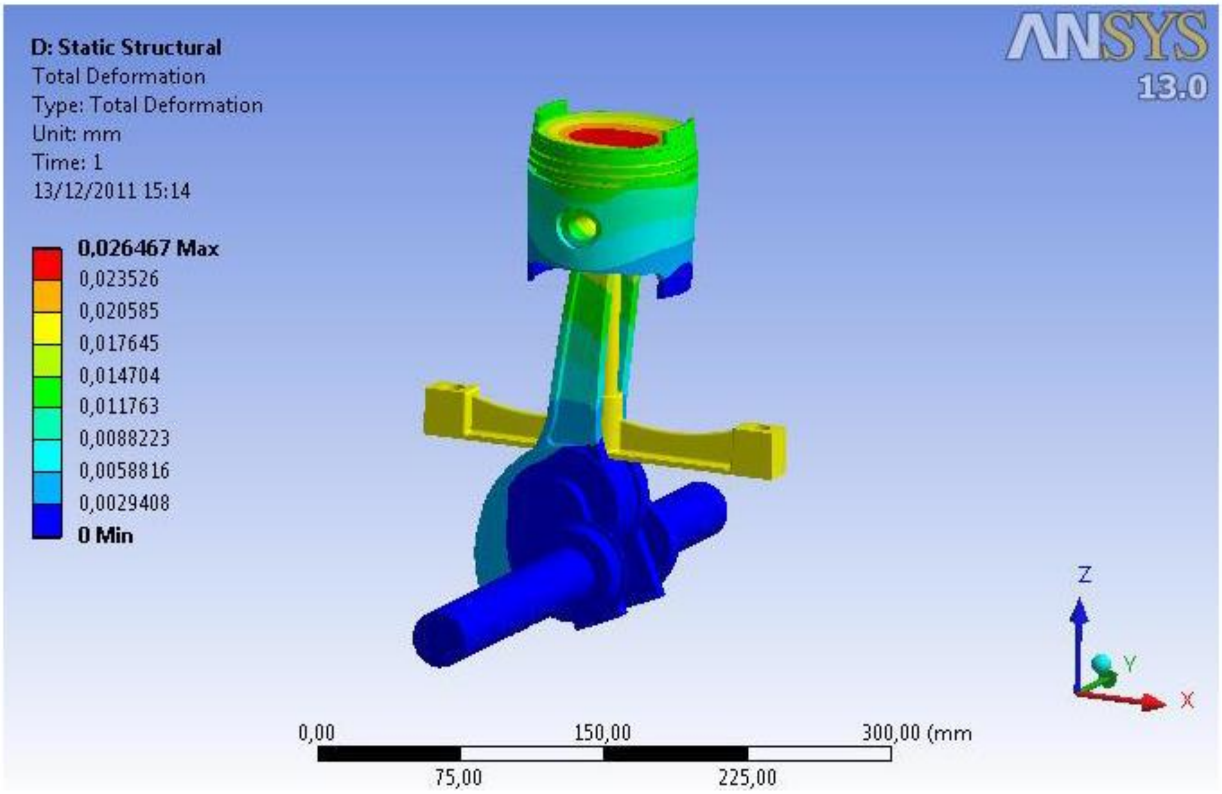

Figure 6. Total deformation of the model

The total deformation shown on Fig. 6 is within the expected and desired values, no high deformations are present in any part of the assembly. Figure 7 is the section view of the regular piston's directional deformation for the X and Y axis. These were the parts that resulted on the higher deformation of the entire assembly.

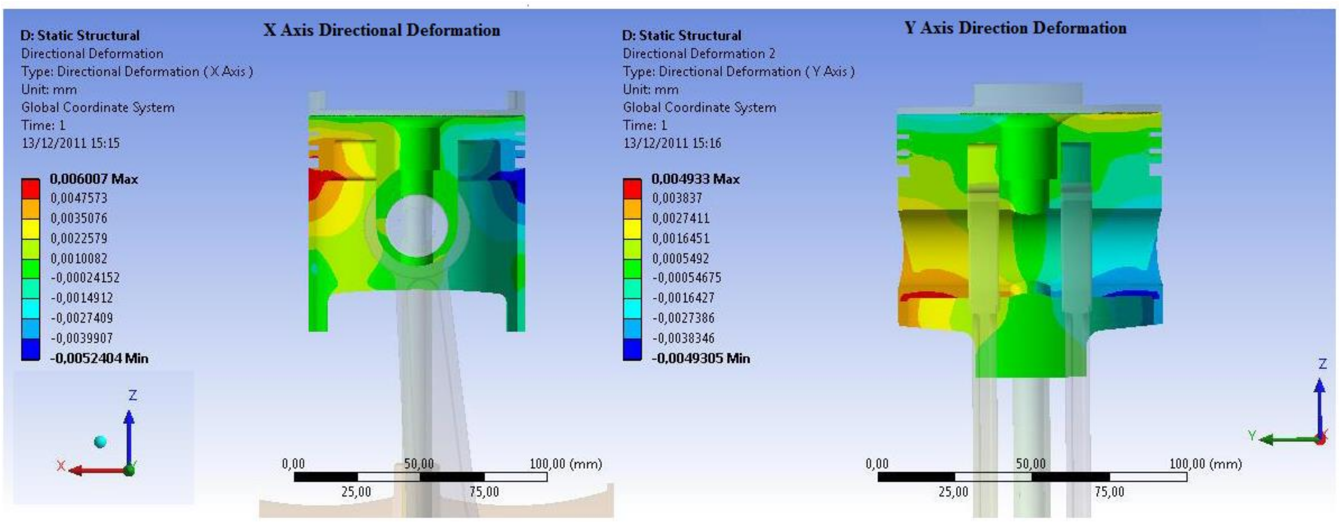

Figure 7. Regular Piston's directional deformation

The directional deformation shown on Fig.7 for the Regular piston on both X and Y axis, as the direction deformation for the Smaller Piston show on Fig. 8 are within the expected values, below of the clearances usually adopted on an IC Engine.

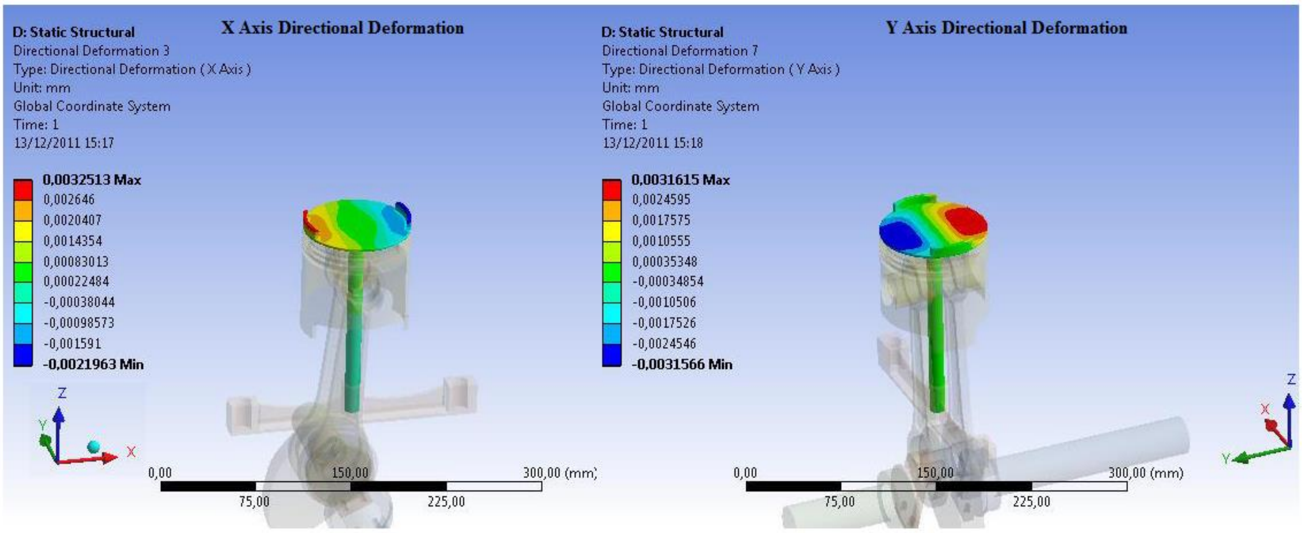

Figure 8. Smaller Piston's directional deformation

The other aspect that needed to be verified were the stresses on the parts of the assembly, therefore, selecting both pistons, since they were the parts with the higher deformation and stresses, Fig. 9 presents the equivalent Von Misses stresses that the parts are under while on the expansion stroke, around 20 degrees after the TDC.

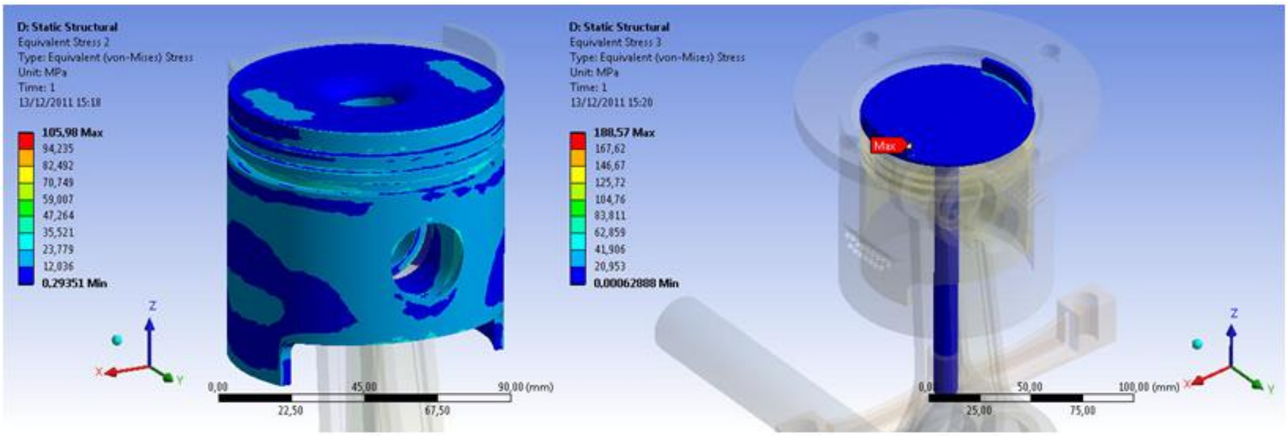

Figure 9. Von Misses Stress on both pistons

3. CONCLUSION

Following the calculations shown on Tab. 2 and 3 for the conventional Otto cycle and comparing to the equivalent Three Stroke Engine cycle, the results show that the intake volume is smaller than the expansion volume, this way the TSE works on an over expanded cycle, similarly to the Atkinson cycle. This increases the efficiency as well as decreases fuel consumption.

The number of cylinder of the TSE is also lesser than the Otto conventional engine, which reduces its weight. On Tab. 2, the number of pistons affects directly the total volume of the engine, 1.0 liter for TSE and 1.6 liter for Otto, this results in a loss of power when using the TSE engine, which is expected due to the intake volume being smaller than the expansion volume.

Although there is a loss in power, there is an increase in thermal efficiency of 11%. This analytical approach shows that the use of TSE could be feasible.

To verify if the parts would withhold such stresses of an IC engine, the structural analysis was made and showed that both deformation and Von Misses stresses are within the expected limit values. Some concentrated stresses were found in some corners of the models, but these are expected since both representation of the parts and the analysis environment were simplified to reduce computational time. Some errors are expected due to these simplifications, however this was a first approach to verify the TSE concept for its performance and its modeling.

One factor that was not taken in consideration was the deformation due to the high temperatures within the combustion chamber, the numerical analysis of the combustion could bring complications and non-valuable results. A future work considering thermal effects will be made so the verification can be improved.

Therefore, for what has been presented in this paper it can be concluded that the objective was achieved and that the results collaborate for further research and improvement of the Three Stroke Engine.

4. AKNOWLEDGEMENTS

The authors thank the educational institution Centro Universtiário da FEI for supporting the research with its simulation labs and instructors that helped developing and enhancing the engine system.

5. REFERENCES

PULKRABEK, Willard W.,2004. “Engineering fundamentals of the internal combustion engine” 2 ed. New Jersey: Prentice-Hall

GARCIA, Oswaldo.,1988. “Motores de combustão interna” São Paulo: DER

SAMUEL, Stephen ; PRAGADA, Anuranjini ;WEEKS, Eric.,2007. “Basic And Intermediate Nx5 Modeling, Drafting, And Assemblies” [S.l]: Design Visionaries

ALVES FILHO, Avelino.,2006. “Elementos finitos: a base da tecnologia CAE” 5. ed. São Paulo: Érica

6. RESPONSIBILITY NOTICE