Improving Slider Window Design on Piston Mold Casting using Finite Element Analysis Aproach

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Abstract— World car sales data for 2017 reached 91 million units. Car sales in Indonesia reached 1.07 million in 2017. If 1 car has 4 cylinders, in 1 year the number of pistons that must be produced for Indonesia reaches more than 4 million pistons or around 16 thousand / day. This does not take into account the number of pistons in two-wheeled vehicles and other engine combustion machine.Pistonis an important part of a vehicle. The D30D Series piston is a piston series that has an ecoform formation, which requires a special slider window mechanism to make the ecoform shape. In the piston production process, the problem that arises is the high voltage on the slider window in the mold, which causes a high intensity of damage to the slider window which is 52 times damage in one month.The previous study had noticed thatthis kind of manufacturing process generates high tension.Another study proposed sheet metal fabrication method but it had limitation in minimum material thickness. This paper aims to investigate the problem and possible improvement in slider window design by reanalyzing the model using finnite element method approach. Considering the time and cost efficiency during this study, simulation and practical testing were used. Finally, this study deliver a new design that gave the defect downs and also lower cost losses. However, the longer trial should be taken to verify and ensure the reliability lastly for 1 month to find out the real life condition and sustain performance.

Keyword— casting, piston casting, repair, finnite elementanalysis ,mechanical voltage ecoform.

I. INTRODUCTION

At present, the number of piston manufacturers is still limited, especially the manufacturers for automotive pistons. The piston manufacturer company produces various kinds of automotive pistons for various products such as 4-wheeled vehicles, 2 wheels, tractors and others.Based on Business Monitor International's report, world car sales in 2017 reached 91 million, and reached 94.3 million in 2018. The increase in world car sales ranged from 4% annually. Car sales in Indonesia in the first half of 2018 reached 661 thousand, and reached 1.07 million units during 2017.

In simple terms, the number of car piston that must be produced for Indonesia reach more than 4 million piston units / year or around 16 thousand / day.

One of the products published is the D30D piston series used by wheel 4 vehicles. Pistons are not common, the D30D piston has an ecoform shape on the window, which serves to increase the piston mass, resulting in a more optimized piston.The Ecoform piston is a piston with a different concept, the result of the development carried out by MAHLE, which has special shapes and grooves for the necessity of weight alleviation [1].MAHLE is a manufacturer of automotive components from Germany.

The making of the D30D piston starts with the casting process, that is, the liquid aluminiun printing process becomes a formation made by the end of the piston that will be made with the aim to facilitate the next process. Without exception the D30D ecoform section. This section has the casting characteristics finished while the piston is formed from the casting results rather than the machining process. Under the surface of a ring groove or commonly called an undercut.To make ecoform formation through the casting process, need additional component, namely the ecoform slider window component which allows the ecoform shape to be formed without damaging the other parts.

The condition of the slider design that is currently used still has problems, namely, the high intensity of damage to the slider window components. The damage reaches 52 times damage in one month or about 2 times damage in a day. The damage that occurs in the casting process is caused by various conditions [2,3,4,5,6,]. Based on the initial analysis, the damage is affected by high mechanical stress [7,8,9]. The effect of the damage, the component must sustain repair process where the casting process becomes stopped.

Another study proposed sheet metal fabrication method but it had limitation in minimum material thickness. In this process, the character of thickness, hardness, deviation of size on the longitudinal axis of the piston is evenly distributed and as expected. Likewise the variation of micro hardness on the piston surface. However, on the lip (edge) the piston is found to be a relatively larger voltage [10]. Considering the important role of pistons in combustion engines, piston reliability must also be analyzed and verified [11].

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Other researchers tried to do mechanical stress reduction using the method of making thin films (films) through the provision of lubricant fluid [12].

Some researchers suggest that fluidity can be used to manage the stresses that arise. Fluidity is a reciprocal viscosity where better fluidity will correct the existing voltage. This is also influenced by the increase in pouring temperature which will also speed up the filling speed of the material in the mold. But also need to be aware that the increase in pouring temperature that is too high will damage the sand in the gating system and the mold wall, and the worst effect is the appearance of a rough surface on the product produced [13].

Finally, this study attempted to deliver a new design that takes the defect downs by recalculating the tension using finnite element analysis method approach. In order to do so, the parts were remachining as designed and tested using simulation as well as practical model[14]. However, the longer trial should be taken to verify and to ensure the reliability lastly for 1 month to find out the real life condition and sustain performance.

II. RESEARCH METHODOLOGY

A. Piston and the Process

Piston is an engine components that complement the combustion chamber along with cylinder blocks and cylinder heads. The piston functions as a moving part of the combustion chamber, and serves to convert the energy that arises to become a mechanical movement and then forwarded to the crankshaft [15]. In the system it can be seen that the piston has a very important function in the engine cycle, in producing combustion power, and converting combustion energy into movement.

According to the manufacturing process, the piston is divided into two types, namely the piston produced by forging or piston forging and the piston resulting from the casting process. Casting is the process of printing an object by flowing molten metal into the mold.

a. Piston forging

Piston forging has solid aluminum raw material. Solid aluminum pieces are heated but do not melt. Next it is formed by being forged or beaten. Because it is made by being hit, the piston forgings have a stronger nature.

b. Piston Casting

Piston casting is made through a casting process. The casting process is the process of pouring liquid material such as metal into a mold, then allowed to cool so that it matches the shape in the mold. After casting, the piston must go through the machining process to get other shapes such as ring grooves, pin holes, valves and other parts.

In the casting process, mold is usually called mold. Mold consists of several components such as Top Core, Core Set, Embang, Holder Embang, and other components. What will be discussed in this paper is the Slider Window component.

B.Mecanique Tension

Mecaniquetension is the load received by the molecules of objects in each unit area of the cross section. The tension indicates the force of style that causes changes in the shape of the object. Tension is defined as the ratio between forces acting on objects with a crosssection area of objects. Mathematically written:

$$\sigma = F/A \quad (1)$$

where σ is the tension (Pa), F is the force (N) and A is the crosssection area (m2).

C. Tensioncause thermal

In general, each heated component will experience expansion. Thermal tension occurs because of the inhibition of the expansion process caused by the retention of the expanding part [16]. To calculate long expansion coefficients, the following equations can be applied.

$$\sigma = E\ \alpha\ \Delta T \quad (2)$$

where E is the modulus of elasticity (Gpa), ΔT is the increase in temperature (oC) and α is the long expansion coefficient.

D. Tension causeswipe style

This tension occurs due to friction on the surface of the object. To find out the force produced the following formula can be used.

$$f = \mu\ .\ N \quad (3)$$

where f is the swipe force, μ is the coefficient of swipe and N is the normal force.

In addition to these tension, there are also stresses due to pressure. This tension occurs due to a reaction that arises in an object because of the pressure given to the object.

E. Finite Element Analysis Method

Finite element analysis method is also known as finite element method (FEM). The basic concept of FEM is to solve the problem by dividing the object of analysis into finite small parts. The small parts are then analyzed and the results are combined again to get a solution for the whole section.

To prove the accuracy of FEM analysis, carried out a validation process first, namely a process that tests the mathematical calculation ability of a model (testpiece) [17,18]. In the FEM validation process, there are three methods, namely:

1. Experiment

The experiment was conducted by comparing t he results of the FEM analysis with the

experimental results. The closer the results of the analysis to the experimental results, the better the results obtained.

2. Comparing with analytical solutions
   Analytical solutions are obtained from simplified models, making it possible to obtain analytical solutions. The analytical solution is then compared with the results of the analysis.
3. Using Intuition
   This method is the simplest method because it only uses the knowledge we have. The disadvantage of this method is that the accuracy of the FEM cannot be known certainty.

FEM calculations are now made easier by using software. To find out the accuracy of the FEM software, conducted the comparison the results of calculations, namely data of experiment result with the data of trial result [19,20,21]. The tolerance limit for errors in the validation process must be below 10% so that the results of the analysis can be declared valid [22]. The software used during the analysis process is solidworks software 2014 that has the ability to perform static analysis with thermal and pressure loading so that it is capable of analyzing the D30D slider window components.

F. Improvement Parameters

Improvement Parameters are important things that are known as determinants of the improvement process. Whether or not an improvement begins with determining the parameters of improvement [23]. Other researchers have conducted many similar studies with various approaches to obtain optimal improvement in the piston casting process.

By utilizing the concept of root cause analysis that is commonly used by companies, and assisted by colleagues from the engineering team using 7 tools commonly used in the Quality Control Circle process in the company, improvement is done by looking back at the damagedatas and irregularities data in the field within 1 month From these data and supplemented with other data, improvements are made to the important points of the component which are believed to provide solutions to existing problems.To get optimal improvement, do the repair process iteratively and experimentally.

G. Research Framework

Research and various studies related to the casting process on piston products have been carried out by many researchers. Based on previous research, improvement can be achieved through simulation stages and conducting experiments both in the casting process and in the design process itself. However, only a few studies and studies of pistons and castings have been carried out with experimental processes. Usually the study is conducted with a focus on the simulation process.

In this study, improvement was carried out through various experiments, carrying out a redesign process taking into consider the data obtained, through the process of observation, interviews and literature studies. The interaction between the parameters is determined through the observation process of the data in the field and the data generated through the calculation process. In addition to study data, damage data is also used as supplementary data in the redesign process. The main target of this study process is to get the results of the design where the stresses that appear are within the allowable threshold.

This study will follow the steps as follows:

(1) Collecting component data and processing data

(2) Design of the D30D slider windowcomponent

(3) Doing the tension analysis using simulation using Solidwork 2014 software to obtain the optimal combination of parameters where the tension on the component is already smaller than the previous data.

4) The manufacturing process of theD30D slider windows.

(5) Quality check to ensure the shape and size of the components are in accordance with the standards in the working drawings resulting from the redesign.

(6) Results evaluation is carried out on the D30D slider window component to find out the results of the improvements that have been made, and whether they are in accordance with the objectives at the beginning.

H. Product Data

This study focuses on automotive pistons with the D30D series produced for 4-wheeled vehicles. These pistons are manufactured using a casting production system and then machined to obtain other forms. This piston has an ecoform formation found in the window section located behind the ring groove. Ecoform serves to reduce the mass (weight) of the piston so that performance can increase. The process of making a rather complex ecoform formation requires a special mechanism so that the other piston parts are not damaged. Figure 1 illustrates the ecoform formation (red circle) which is behind the roove ring surface.

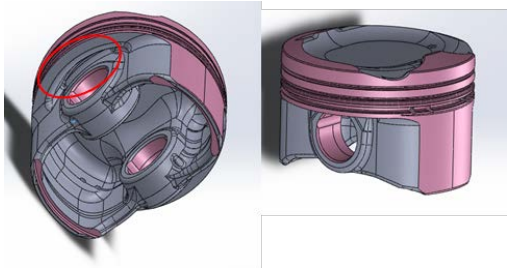


Figure 1. Ecoform Formation in the D30D Piston

The special mechanism needed for making ecoform forms is the slider window mechanism. Slider window is one component of a mold casting unit whose task is to make ecoform formations on the D30D series pistons. Figure 2 illustrates the initial draft window slider.

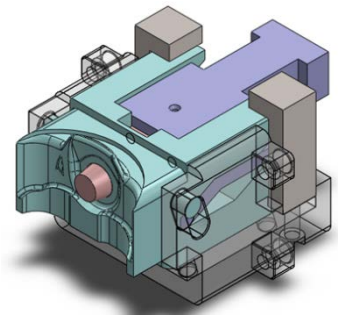


Figure 2. Form the Slider Window

The D30D slider window piston component is made of SKD61 material. SKD61 material is included in the tool steel material group, mold steel, and midde carbon steel. The material properties of SKD61 are high hardness and wear-resistant properties after getting heat treatment. SKD61 has good hardenability and has a stable level of thermal fatigue resistance. This material is not only able to withstand a large mechanical tension, but also able to withstand tensionthat cause thermal occurring repeatedly. This material is widely used to produce tools and cutting tools, cold / heat work dies, and other supporting tools in piston manufacturing processes, valves, punching machines, and other tools that work at relatively high temperatures . With such material properties, it is expected to be able to meet the demands of working conditions that must be faced by the slider window. The sider window component specification is shown in Table 1.

Table 1. Specification of the D30D Piston Window Slider

Parameter	Value
Material	SKD61
Working temperature	350 °C
Weight	3.6 Kg
Hydraulics Tension	70 Bar

The D30D slider window unit consists of several components that have their own functions. Figure 3 is an exploded view from the slider window.

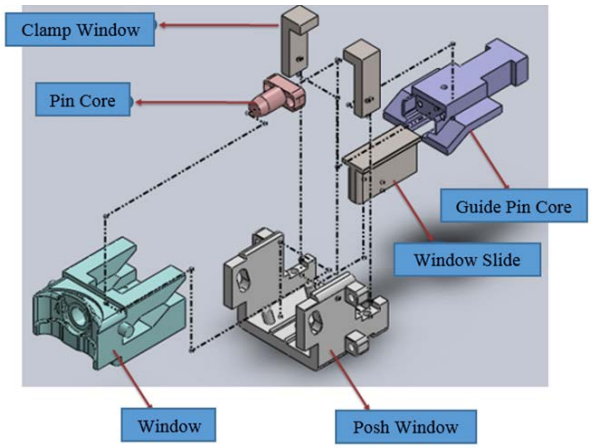
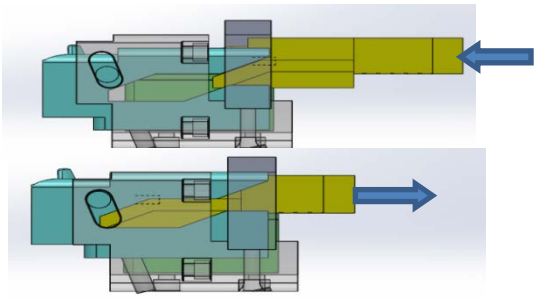


Figure 3. Exploded View Slider Window

From figure 3, the names of the components and their functions can be described. The window component functions to form the ecoform and window. The posh window component functions to bind components with an outer mold. The slide window functions as the core guide pin movement path. Guide core pins function as window and core pin boosters. The core pin functions to form a pin hole in the piston and the last is a clamp window that functions as a stopper at the top of the window.

A wedge angle mechanism is used in the slider window to lift and push the window to reach the desired position. In this mechanism, the pin holder is driven using a hydraulic thrust. The window pushed by the pin holder will rise at an angle of 17 o according to the guide in the posh window. When the casting process is complete, the pin holder will be pulled back using a hydraulic puller to return to its original position. Figure 4 illustrates the movement mechanism of the slider window.



Gambar 4. MekanismeGerakan Slider Window

III.RESULTS AND DISCUSSIONS

G. Simulation Design for Parameter Improvement

Improvement parameters and analysis are needed at the beginning of the discussion to get a relationship model and parameters needed for the improvement process. The parameters observed are stresses due to frictional forces, stresses due to thermal forces and stresses due to hydraulic pressure. These stresses cause the repair process 52 times in one month.

The slider mechanism that uses the concept of a wedge angle causes friction and makes the tension that arise become bigger. Table 2 below describes the total force and tension that occurs in the old design.

Table 2. Tension causeOldDesignFriction

Friction Field	Koef. Swipe	Surface area (m^2)	Mass (kg)	Swipe Style (N)	Tension (Pa)
Window – Guide Pin Core	0.74	0.00045	1.3	9.62	10688.9
Guide PC – Window Slide	0.74	0.0015	0.71	5.25	3495.9
Window – Guide PC 27°	0.74	0.000771	1.158	8.57	11115.43
Pin – Window 17°	0.74	0.0012316	1.24	9.20	0.0012316
			Total	32.64	25300.23

High temperatures in the piston casting process give rise to thermal tension. The tension experienced by the slider window components is quite high, especially in parts that are directly in contact with the casting material. This is done through a simulation process that is to provide a working temperature of 350 oC on the surface of the slider which is in direct contact with the casting material. In this way it is known that in the section marked with a red circle the tension that occurs is 1407.2 MPa, which exceeds the yield strength of the SKD61 material, which is 1341 MPa. Figure 5 describes the parts that are experiencing excessive tension.

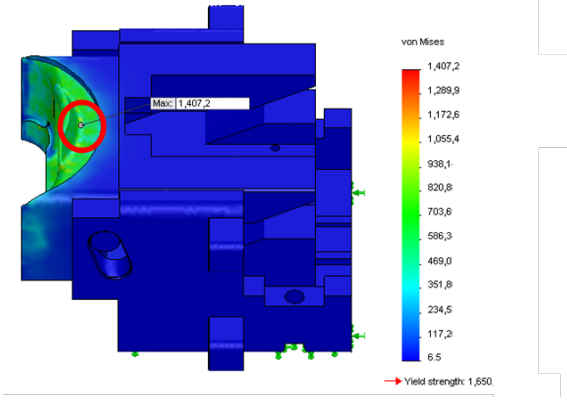


Figure 5. Thermal Tension in the Old Design

The pressure needed to drive the slider window component is 70 bar, equivalent to 7 MPa so that the simulation process is 7 MPa. In figure 6, it can be seen that the tension arising from hydraulic pressure is 488.5 MPa and occurs in the wing window meeting section (part with a red circle). This tension causes a broken window wing.

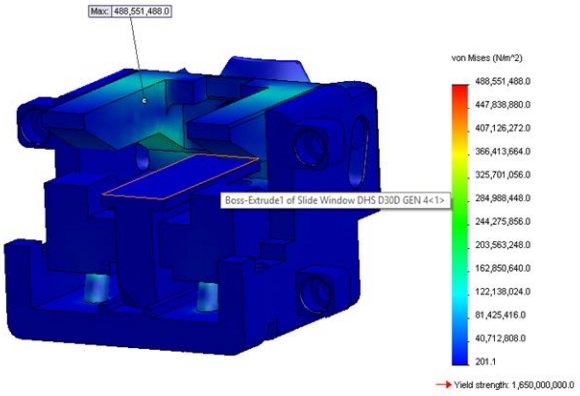


Figure 6. Tension of Hydraulic Tension on the Old Design

H. Design Improvement

The next study is to make improvements to the critical part and is considered to be inappropriate through the redesign process. Through these stages the optimal parameters are expected to be obtained using the chosen approach. From the results of previous studies, six main components were found with each of the critical points:

1. Posh Window

In the POSH window there is a guide slot that serves to prevent errors in the position of the window when rising and pin to reduce the error mechanism.

2. Window

In the window there is a guider on the front that adjusts to the posh window position. The window is made separate to reduce thermal stress due to the back window.

3. Back Window

The slope level in the back window field is made not too large to minimize friction force and to minimize the touch area with a step made on the front window.

4. Slider Pin Holder

The stack of windows is repaired to eliminate the hanging mechanism and a guide is made on the core pin holder to maintain the position of the core pin.

5. Pin Core

Shifting the position of the pin (offset) is removed so that there is no difference between the left and right.

6. Slider Adjuster

The position of the groove is shifted (offset) as far as 0.65 mm in the direction following the shape of the piston geometry.

The redesign was carried out by utilizing the data obtained in previous studies so that the expected stress, fracture risk, and other potential damage can be minimized.

The mechanism used in the new design is relatively the same as the previous design. The push system and the use of wedge angles to lift window sections are still used.

I. Validation for Optimum Improvement

To guarantee the accuracy of the results of the analysis process, the validation stage must be done first by comparing the calculations with the analytical solutions produced from the simplified model.

The tension validation process cause pressure or tension pressure is carried out in a simulation by giving an axial load of 1000N to a cylinder like the following figure 7.

Figure 7. TestpieceTension on the Cylinder

Taking into account the thrust force of 1000 N and the area of 1962.5 mm2, a voltage of 0.509 N / mm2 is obtained. After manual calculation, the next calculation is done using software for the finite element method as shown in figure 8. Taking into account the thrust force of 1000 N and the area of 1962.5 mm2, a tension of 0.509 N / mm2 is obtained. After manual calculation, the next calculation is done using software for the finite element method as shown in figure 8.

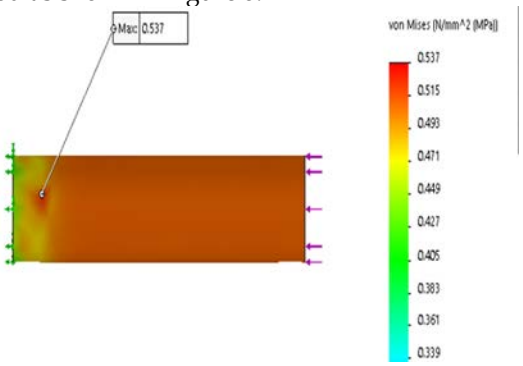


Figure 8. Calculation of Tension Using FEM

Figure 8 illustrates the Tension arising through calculations using the FEM software whose size is 0.537 MPa. Given that MPa units are equal to N / mm2, the calculation of accuracy can be done by comparing directly. The level of accuracy is obtained by comparing the results of manual calculations with the results of software calculations and expressed in percentages. The accuracy rate is 94.8%.

Thermal tension validation is also carried out for the purpose of guaranteeing the accuracy of the results. Validation begins by manually calculating the testpiece with a size of Ø 25 x 125 mm as shown in figure 9.

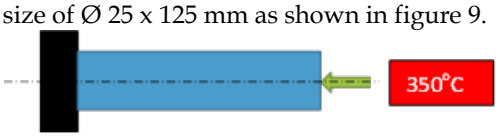


Figure 9. Thermal Stress Tension

From the mathematical calculation, obtained the thermal tension value is 1279.25 MPa. After doing the calculations manually, then do calculations using software for the finite element method as shown in figure 10.

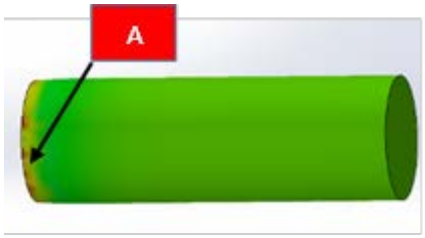


Figure 10. Calculation of Thermal Tension with FEM

In figure 10, the voltage arising at point A is 1270 MPa. Like the previous calculation, the accuracy calculation is also done in this section. The accuracy is 99.3%.

J. Experiment Result Analysis

Figure 11 below shows the conditions that occur in the casting process. The part that is exposed to heat is the surface of the window. The temperature seen is 350 oC. Thermal tension arises because of the influence of temperature. The highest tension is 1163.4 MPa which is located in part A or the ecoform section. This tension is below the yield point of SKD61 material, which is 1341MPa.

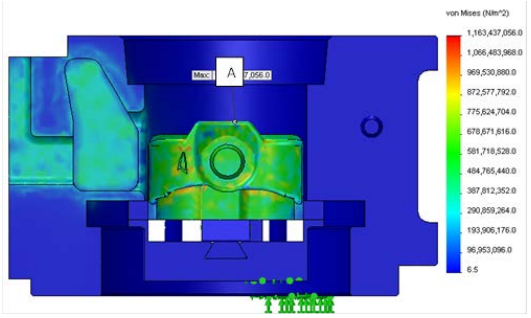


Figure 11. New Design Thermal Tension

The pressure from the hydraulic system has a large influence regarding the emergence of tension on the slider components. Figure 12 displays the tension present, which

arises cause the pressure from the hydraulic system.

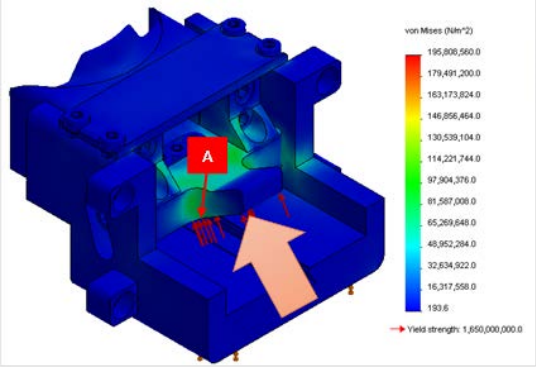


Figure 12. Tension cause the hydraulic system in the New Design

The cream arrows indicate the direction of pressure that works. In the new design, the highest pressure that arises is 195.8 MPa and occurs at point A. This tension is lower than the original tension of 488.5 MPa.

The tension caused by friction that arise is also analyzed in this study. The tension analysis cause friction that occursis described in the following table 3, which is obtained from mathematical calculations.

Table 3. Tensioncause New Design Friction

Friction field	Luas Area (mm^2	Massa (kg)	Gaya Gesek (N)	Tegangan (Pa)
Body of Pin - Window	1319.17	0.54	2.16	1637.40
Inclined plane	538.85	0.54	2.16	4008.54
Dove Tail	921	0.71	2.84	3083.60
		Total	7.16	8729.54

The tension due to friction in the slider window component in the new design is 8729.54 Pa, while the voltage in the old design is 25300.23 Pa. In the new design there was an enough significant decline.

IV CONCLUSIONS

Based on simulations, experimental studies and simulation results equipped with mathematical calculations using the FEM approach, it can be concluded that the most effective way to reduce the intensity of damage to the D30D silder window component is by redesigning the component. By doing a redesign, it is found that the tension reduction is due to the thermal, tension due to hydraulic system pressure and friction tension. With the decrease in tension, the potential of the slider window component to change shape until the damage will be lower.

Experiments with redesign reduce the existing tension. The reduction in detail can be described as in table 4 as follows.

Table 4. Comparison of Old and New Designs

The different	Old Design	New Design
Mass (Kg)	3.6 Kg	2.9 Kg
Tension cause Thermal	1407.2 N/mm^2	1163.4 N/mm^2
Tension cause Pressure	488.5 N/mm^2	195.8 N/mm^2
Tension cause Friction	25300.23 Pa	8729.54 Pa
Number of Components	7	5

The validation process that has been taken to maintain the level of accuracy of results is at a good level, which is above the figure of 94% or less than 10%. Thus the improvement method using the analysis element finite approach can be considered as a valid method.

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