Durability Studies of Remanufacturable Components for Extended Life Cycle

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ABSTRACT

The concept of remanufacturing that requires automotive components to enter a new life cycle in 'as new' condition is certainly a challenge to the remanufacturers. A remanufacturable component has to be designed for durability to ensure that its functional performance is retained after reaching its end of life. To date, there is no systematic approach in ensuring the durability of remanufacturable components to ensure that they are fit for use in their subsequent life cycles apart from visual inspection and testing after the reassembly process. Therefore, it is necessary to conduct an evaluation on the damage and life cycle of remanufacturable components. In this study, an automotive air conditioning compressor was used as a case example. The function of a compressor is to compress refrigerant inside the air conditioning system. After years of usage, the internal parts of the compressor such as bearing, o-rings and seal tend to be damaged and become unusable. However, its casing known as the core has the potential to be reused for several life cycles through remanufacturing. A simulation test on the compressor comprising static and fatigue tests are carried out and the results show that the compressor casing has the ability to be remanufactured since there are only minimal damage and a large number of life cycles. Findings from the study will assist manufacturers in understanding the importance of designing for durability for purposes of recovery strategies such as remanufacturing, which serve as a new demand in the automotive industry.

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Introduction

Remanufacturing is one of the growing industry which has obtained recognition as an economically viable activity together with its benefits in preserving the environment. Remanufacturing is one of the main industry in Europe. Xerox, Caterpillar, Volvo, Ford and Bosch are amongst the large companies that have been involved in the remanufacturing business. Bosch products such as starters and alternators are examples of remanufactured components which have been sold widely. The demand for remanufactured components has increased due to cost effectiveness since remanufactured components are much more cheaply compared to the new ones. Another advantage of choosing remanufactured components is the quality and performance are the same as new parts since a warranty will be given to these remanufactured components [1]. The idea of remanufacturing comes from the principles of the 6R approach for sustainable product development namely reduce, reuse and recycle, redesign, recover and remanufacture [2]. Each approach has its own significance in ensuring environmental sustainability. Reduce refer to the reduction of energy used together with the material and resources during manufacture. Not only that, it includes a reduction in emissions produced during a manufacturing process. Reuse refers to the using back of product or components after its first expected life cycle. Recycle is the process of converting waste into a new material. Meanwhile, recover are the recovery of parts or components that have been used which later be used in the next life cycle. Redesign is the method of redesigning a new part which uses the same resources and material from the previous part after its end of life. Remanufacturing is the method for re-processing of used parts after their end of lives to be used as new parts with the same function and quality after undergoing several processes such as disassembly, cleaning, inspection and testing. Remanufacturing is the most preferable recovery method as it does not only save the environment by reducing the consumption of new material but also, it offers parts which have the same performance and quality as the new ones at a lower price.

Remanufacturing can be defined as the process of giving life for a used product in order to become a like-new product that has a warranty which is the same as new [3]. It can also be defined as the restoration of worn out, used or discarded components to become a like-new component [4]. The process of remanufacturing started from obtaining the end-of-life components from consumers. During remanufacturing, the components are cleaned, inspected and disassembled. Damage or worn out components are replaced with new ones and the process continued with reassembly and finally testing for functional performance according to manufacturer's standards and specifications. In remanufacturing, cores will be retained while worn out parts are replaced.

There are many factors that need to be considered in order to ensure that remanufacturing can be carried out efficiently. This includes ease of disassembly and assembly, the durability of parts, ease of cleaning and modularity of the parts [5]. Durability is one of the important considerations in remanufacturing as a durable product will have a longer lifetime thus allowing products to undergo an additional lifecycle results from the remanufacturing process. For a part to undergo remanufacturing, it needs to have a high wear resistance, does not damage easily and has a sturdy structure. This is because durability is not only focusing on part safety but also for the purpose of having a longer life span, to allow for usage in multiple life cycles. Therefore, methods in designing for durability is important for the development of remanufacturable products.

Automotive is one of the industries that are heavily involved in remanufacturing. In the automotive industry, remanufacturing has been recognised as the most value-added alternative in reducing the amount of materials used while offering products with a quality as good as a new one. In a car air conditioning system, the compressor is one example of a commonly remanufactured component. The function of a compressor is to compress the refrigerant that comes in at low pressure and releases high pressure into the system. The compressor consists of several numbers of the piston inside which function to compress refrigerant depending on the car model. Compressor is mostly broken or unable to function due to some damage to the internal components such as the ring or gasket. However, the casing normally does not suffer any serious damage or wear hence making it a potential component to be remanufactured.

Compressor is one of the main components in an air conditioning system and it is one of the high-value parts in the system. Due to this, the compressor is suitable for remanufacturing due to its demand and also the compressor would normally suffer damage to its internal parts such as the ring and gasket while the casing remains intact. By studying the durability of the casing, its ability to be used for a long time thus supporting remanufacturing can be ascertained. This research will focus on the stress, strain, displacement, factor of safety, damage percentage and number of life cycles produced by applying the FEM method. The results will provide an understanding of the ability of the casing to be used for a longer time or for a second or third life cycle.

PERODUA which is known as the *Perusahaan Otomobil Kedua Sendirian Berhad* is known to be the largest car manufacturer for a compact car in Malaysia as it has produced cars like Kelisa, Viva, Myvi and Axia. One of the highest selling car by PERODUA is the Myvi. It has been introduced since 2005 and up until 2014, it remains to be the top selling car in Malaysia. Recently, PERODUA has announced that the Myvi will reach its one million production units between the second quarter of 2017. Figure 1 shows the example of PERODUA Myvi which currently in the market. The Myvi use the air conditioning system which consists of the radiator, condenser, expansion valve and also the compressor. For this model, the compressor is of the piston type which uses a piston inside. In this paper, the evaluation of fatigue life for the compressor is conducted using the finite element method.

Figure 1: PERODUA Myvi

Methodology

Finite Element Method (FEM) is known to be one of the most common methods for simulation in identifying the fatigue life of a product. FEM basically creates a finite number of sub-areas within the element which is later solved mathematically. The number and size for the finite elements vary according to the user and all this will affect the results and the amount of computing time needed. FEM has been used for identifying stress, strain, elasticity, the flow of liquids, and many more. Fatigue analysis can also be identified using FEM. FEM helps to reduce the time taken for estimating stress, deformation and life cycle when compared to experimental which takes a much longer time for results to be obtained. The SolidWorks software was used to identify the stress, strain, deformation rate and also the damage and life cycle produced for the compressor casing. FEM is commonly used to determine durability based on the result of the analysis. A study was conducted to determine the effect of muffler mounting bracket design in which the simulation indicates that the new bracket design was able to reduce stress in critical areas thus making it becomes more durable [6]. Another study on the effect of axial preload on the aerospace fastened joint was conducted to identify stress location and the study concluded that the increasing amount of preload will reduce the stress amplitude thus making it more durable [7]. In addition, there is also a study to determine the failure on a crankshaft of a diesel engine. The simulation was able to identify the location of stress and its failure. The fillet of the crank pin experienced the highest stress causing it to fail after a certain period of time[8]. These studies indicate that FEM helps to identify stress, strain and also the failure that may occur on a part or components making it as a preferable method for studying the durability of a product.

The compressor casing consists of four parts which are attached together by a long screw. Figure 2 shows the image of the complete casing. Only one part of the compressor which is located beside the rear part of the compressor casing will be simulated in the software. The part was chosen due to the presence of a suction and discharge port for the refrigerant. The suction port is larger than the discharge port due to the lower pressure of refrigerant entering the compressor. In addition, the part experienced the highest pressure exerted by the refrigerant after being compressed by the piston inside the compressor. The material for the compressor is aluminium alloy which is widely used in car components such as the compressor, fuel pumps timing gear and many more. This is due to its lightweight structure together with its ability to withstand the pressure exerted on its body.

Figure 2: Compressor

Results and Discussion

At first, the compressor part is drawn using the CATIA software as per the dimensions of the compressor casing, as shown in Figure 3. It is then imported in SolidWorks for fatigue life evaluation using the finite element method.

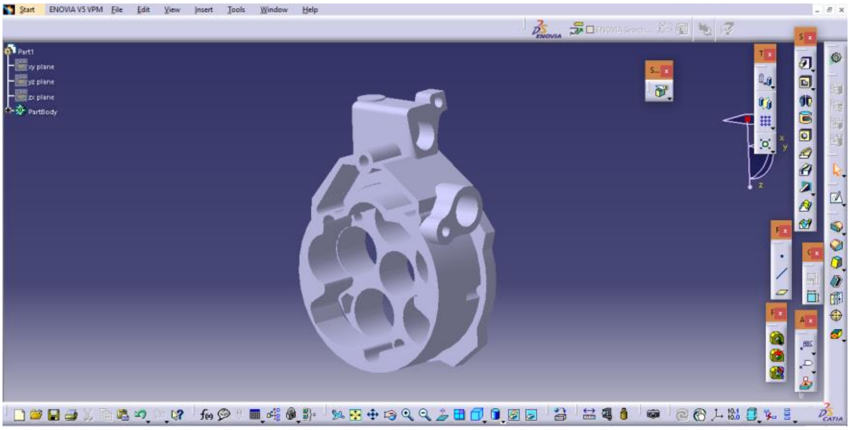

Figure 3: CATIA drawing

Static Analysis

In SolidWorks, two different analyses were conducted namely, static and fatigue analysis. The static analysis evaluated the stress, strain and deformation rate of the compressor casing when the load is applied. In this case, load comes from the pressure carried by the refrigerant. The amount of pressure tested on the compressor body comes from the technical specification of the compressor. The minimum value is 1.67 MPa which comes from the suction port where the refrigerant enters the compressor and the maximum is at the discharge port with 3.53 MPa. The pressure was selected as the factor of analysis since damage to the body inside of the compressor is due to the effect of refrigerant. The body of the compressor does not suffer any critical damage from the surrounding since it experienced only low heat and vibration. The overall mass for the part is 0.487 kg while its density is 2680 kg/m^3. The value is generated automatically by the simulation. Pressure is exerted on the five circular space which is the location for the piston compressing the refrigerant and later sending out to the radiator. Figure 4 shows the location of pressure acting on the body of the compressor. The arrows indicate the direction of pressure acting on it.

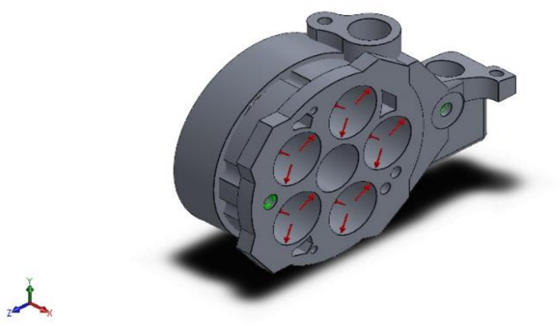

Figure 4: Location of pressure

Once pressure is applied, the parts are meshed resulting in 46354 number of nodes and 27243 numbers of elements. Figure 5 shows the meshing generated from the simulation.

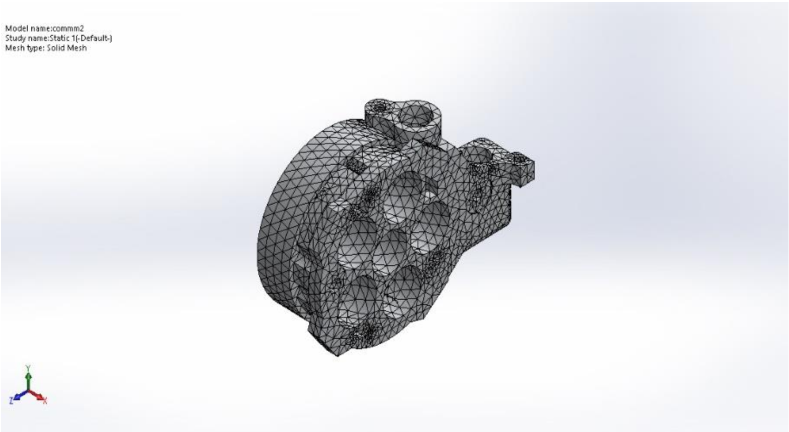

Figure 5: Meshing

Once meshing is completed, the compressor parts are evaluated for stress, strain, the rate of deformation and factor of safety is determined. Figure 6 shows the minimum and maximum stress experienced by the casing. The minimum stress recorded is 3335.69 N/m^2 while the maximum stress is 1.37761 x 10^8 N.m^2. The recorded yield strength is 1.52 x 10^8 N/m^2. Figure 7 shows the results on strain with a minimum value of 7.02713x 10^-8 and a maximum strain of 0.00124552. The maximum displacement experienced by the part is 0.0144959 mm and the displacement does not occur on all parts of the body but only in a small area especially around the circular area as shown in figure 8. Lastly, the factor of safety recorded is 1.1 as shown in Figure 9.

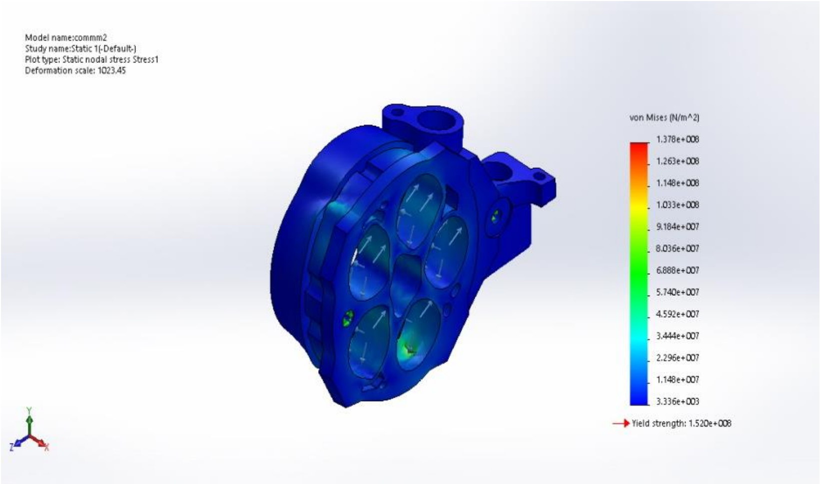

Figure 6: Stress

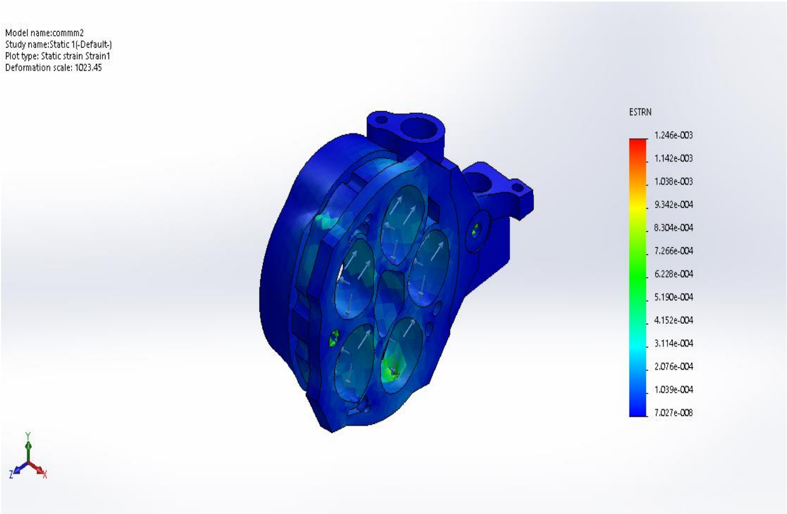

Figure 7: Strain

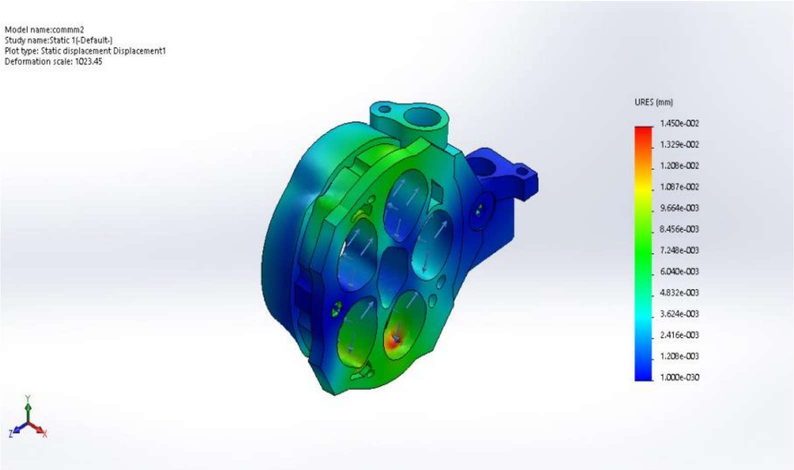

Figure 8: Displacement

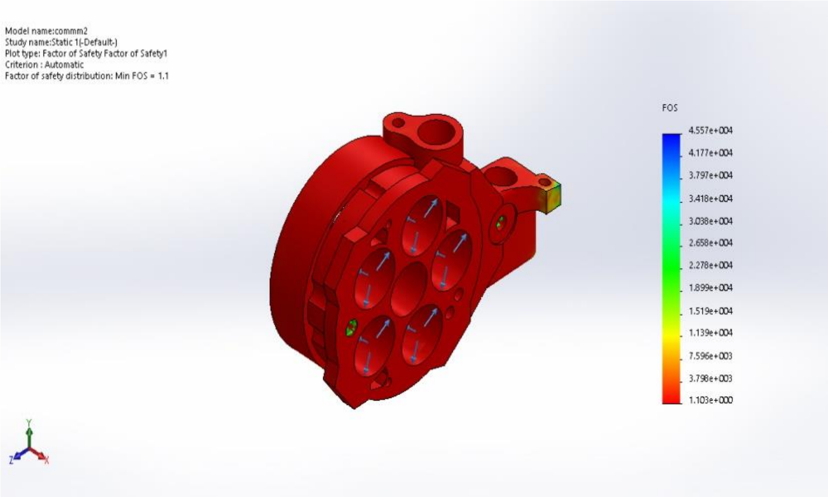

Figure 9: Factor of Safety

Fatigue Analysis

Fatigue Analysis helps to obtain the estimated number of life cycles that the part could have throughout its life. In this analysis, a constant amplitude is applied throughout the whole cycle. An event is set by giving a 10^8 number of cycles with a value of R=0. The value of R=0 because, the compressor can only experience an increase in dimension when maximum pressure is applied and once the pressure is gone, it will return back to its normal dimension. This can be in the displacement data from the static analysis. Two results are shown in this analysis which is the damage percentage and number of the life cycle. Figure 10 shows the image in which a very minimal damage occurs on the casing. Meanwhile, figure 11 shows the expected number of life cycles with a minimum of 507980 cycles and a maximum of 10^6 cycles. It can be seen from the analysis that the whole part has the maximum number of life cycles.

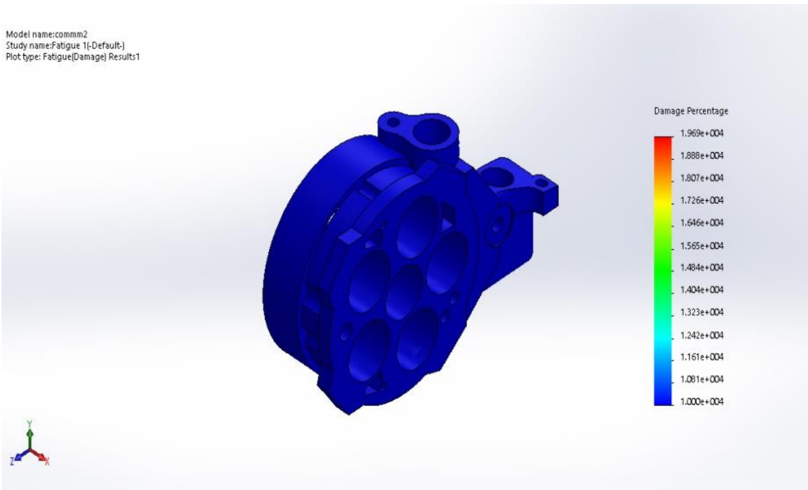

Figure 10: Damage percentage

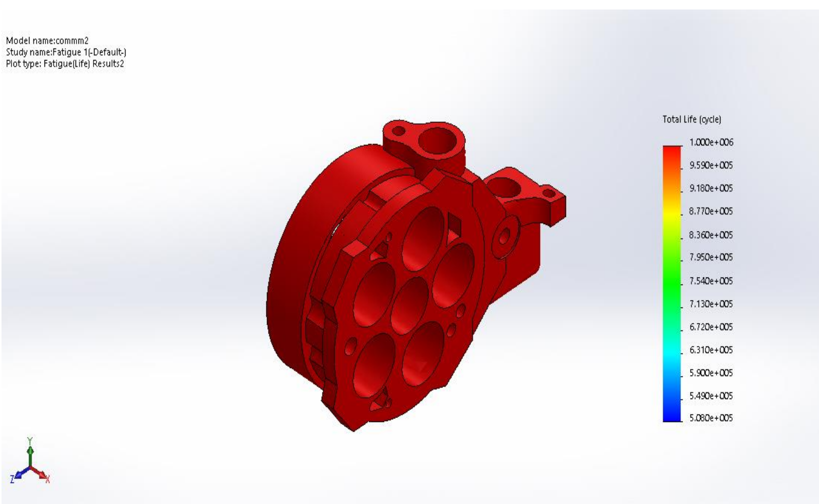

Figure 11: Number of life cycles

From the static and fatigue results, it can be seen that the compressor does not experience failure in term of structure which means that it will not damage or break after a series of tests. Only a small displacement was recorded along with a small amount of damage experienced by the part. The number of life cycles indicates that the compressor can be used for a long time, which is why compressors are commonly remanufactured. The use of simulation helps to identify stress that occurs on the body of the compressor by showing the exact location where stress concentration is the highest. By looking at the results, improvement can be made to reduce the stress concentration. When the part experienced high-stress concentration, it can lead to a high damage and eventually a lower lifetime. This will affect the durability of the part and improvement needs to be carried out to overcome this problem.

However, the number of life cycles generated refer to a single lifetime only. Usually, the compressor will become unusable due to damage not because of the casing (core) but the internal parts. Therefore, it is important for manufacturers to understand the ability of remanufacturable components such as the compressor, to have more than a single life. In remanufacturing the number of the life cycle is very important as this is the main key to supporting the remanufacturing process. Durability is one of the main aspects of remanufacturing. Other factors include modularity, simplicity, and also ease of assemble and disassemble [9]. Although durability is a very important requirement to support remanufacturing, all these factors need to be considered in supporting the life cycle number[9]. Further, an approach for predicting the number of life cycles for the compressor can be very useful for ascertaining durability in multiple life cycles. A previous study has developed a method for determining the ability of an automotive component to be reused using an artificial intelligence (AI) method [10].

The use of artificial intelligence method helps to identify and assess the potential of a component to be reused after its end of life. In addition, an AI method has also been used in designing an automotive part for remanufacturing using the artificial intelligence method [11]. The study focused on material selection based on fuzzy TOPSIS for predicting the type of material to be used in automotive parts and have the potential to be remanufactured after its end of life[11]. In addition, there is a study on life prediction of a reused automotive component based on an artificial intelligence method namely, Artificial Neural Network(ANN)[12]. This indicates the increase in a number of research on the integration of AI methods in automotive applications. Therefore, future works on durability analysis with the integration of AI methods as a technique for estimating the life cycle of parts or components is proposed.

Conclusion

In supporting remanufacturing, an understanding of the aspects of the durability of a remanufacturable components is very important. A reliable and durable product will certainly support environmental sustainability through remanufacturing. A simulation study is presented and discussed in this paper by observing the effect of pressure applied by the refrigerant towards the compressor body using SolidWorks software. The results indicated that the compressor can withstand the pressure and with a minimal amount of displacement. Only a small area in the compressor experienced a large stress and strain. The fatigue results show that the compressor part can have an approximately one million life cycle and only a minimal amount of damage is recorded. This will provide an understanding of the durability of the compressor parts, indicating that the parts have the ability to be remanufactured. In addition, it is suggested that the AI approach can be used to estimate the number of life cycles for the compressor as this will assist remanufacturers to know the limit of their processes

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