Simulation on the Performance of a Driven Fan Made by Polyester/Epoxy interpenetrate polymer network (IPN)

Mohd Fahrul Hassan¹,*, Azmil Jamri¹, Azli Nawawi², Muhamad Zaini Yunos¹, Md Fauzi Ahmad³, Sharifah Adzila¹, Mohd Nasrull Abdal Rahman¹

¹Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia
²Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia
³Faculty of Technology Management, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

Corresponding author: fahrul@uthm.edu.my

Abstract. The main purpose of this study is to investigate the performance of a driven fan design made by Polyester/Epoxy interpenetrate polymer network (IPN) material that specifically used for turbocharger compressor. Polyester/Epoxy IPN is polymer plastics that was used as replacements for traditional polymers and has been widely used in a variety of applications because of their limitless conformations. Simulation based on several parameters which are air pressure, air velocity and air temperature have been carried out for a driven fan design performance of two different materials, aluminum alloy (existing driven fan design) and Polyester/Epoxy IPN using SolidWorks Flow Simulation software. Results from both simulations were analyzed and compared where both materials show similar performance in terms of air pressure and air velocity due to similar geometric and dimension, but Polyester/Epoxy IPN produces lower air temperature than aluminum alloy. This study shows a preliminary result of the potential Polyester/Epoxy IPN to be used as a driven fan design material. In the future, further studies will be conducted on detail simulation and experimental analysis.

1. Introduction

In 1925, the Swiss engineer Dr. Alfred Büchi was the first to be successful with exhaust gas turbocharging, and achieved a power increase of more than 40%. This was the beginning of the gradual introduction of turbocharging into the automotive industry [1]. Nowadays the word ‘turbo’ became fashionable. Equipping the car with turbocharger compressor bring lots of benefit such as increasing the performance, reducing fuel consumptions, and lower carbon dioxide (CO₂) emission that will decrease the air pollution. As for the market domination, only about 6% petrol cars are currently turbocharged compared to diesel cars which are almost 100%. For further enhance of the turbocharger application, manufacturers and researchers continuously seeing for a new method of improvement [2].

A turbocharger is made up of two main sections which is the turbine and the compressor. The turbine consists of the turbine wheel and the turbine housing. Turbine housing works to guide the exhaust gas into the turbine wheel. The energy from the exhaust gas turns the turbine wheel, and the gas then exits the turbine housing through an exhaust outlet area. The compressor also consists of two
parts that is the compressor wheel and the compressor housing. The compressor’s mode of action is opposite that of the turbine. The compressor wheel is attached to the turbine by a forged steel shaft, and as the turbine turns the compressor wheel, the high-velocity spinning draws in air and compresses it. The compressor housing then converts the high-velocity, low-pressure air stream into a high-pressure, low-velocity air stream through a process called diffusion. The compressed air is pushed into the engine, allowing the engine to burn more fuel to produce more power [3]. Compressor wheel placed at the compressor section of the turbocharger that functions to draw the air into the compressor and accelerates it into the engine. Therefore the design of the compressor wheel plays an important role in determining the turbocharger performance. Nowadays, the design of the turbocharger compressor wheel has evolved into very complex shape which is very efficient in increasing the engine performance. Due to the capability of the turbocharger in increasing engine performance, this study presents an investigation of the performance of a driven fan design that specifically used for turbocharger compressor using Polyester/Epoxy IPN material.

Turbocharging system consists of a compressor and a turbine coupled on a common shaft. Turbocharger plays an important role in engine downsizing and reducing exhaust emission and fuel consumption. The high output power of the engine is the results of the expanding exhaust gas in the turbine to drive the compressor and the high intake charge density compared to the natural aspirated engine. The type of compressor used in turbocharger is the radial flow type compressor due to its compact structure, light weight and high efficiency [4]. The compressors are usually investment cast wheel. The design of the compressor wheel has to follow the aerodynamic requirements, mechanical strength considerations and the foundry capabilities. Very thin sharply impeller blades are desirable in order to get higher mass flow and compressor efficiency but in order to keep the levels of steady state and vibrating process low, a blade with robust root is needed [5]. The need for high pressure ratio, large flow range and low inertia turbocharger compressor impeller cause the development of smaller compressor tip diameter, high backswept impellers which in consequence, increase the impeller rotational speeds. Because of this, the rotation induced stresses are very high and the maximum speed of the compressor will be governed by stresses both in the impeller hub and the blades and vibration problems [5].

Turbocharger driven fan or as well called the turbocharger compressor impeller or wheel is placed at the compressor section at the turbocharger. Turbocharger compressor impeller is a radial compressor because it takes in fresh air and accelerates it radially or turns it 90 degrees. This compressor impeller has a complex design which the purpose to suck in the air and compress it before channel it into the engine cylinder. Nowadays, the turbocharger impeller is designed with splitters to increase its efficiency and the most production is aluminium investment casting. There are many types of compressor wheels which each of it has its own advantages and type of use. Figure 1 shows the design of the impeller with the splitters [1].

![Figure 1. Turbocharger compressor wheel.](image-url)

2. Methodology
In the methodology section, several steps in this study have been presented from introduction of driven fan turbocharger, parameters identification, design an existing driven fan, simulation process, and analysis and comparison of results on the fan that made by the Polyester/Epoxy IPN.

2.1. Introduction of driven fan turbocharger
In this stage, it is necessary to know the information about a turbocharger driven fan or also called a compressor wheel. The information about the existing design of the wheel such as the size, shape, weight and materials used need to be known in order to design a new compressor wheel which can produce higher efficiency than the existing wheel. Study about the turbocharger system will help in identifying the parameters which affecting the turbocharger performance and then will make the designing process of the new wheel easier.

2.2. Identification of parameters for turbocharger compressor wheel that affects the performance
The purpose of this study is to increase the performance of the turbocharger by proposing a new material of the turbocharger compressor wheel. The new design should be more efficient than the existing design which is able to draw more air into the engine. Due to that reason, the parameters of the compressor wheel which affect the turbocharger performance are needed to be known. The new design will be analyzed based on the identified parameters so that the new compressor wheel can be designed based on the parameters of the existing compressor wheel. Those parameters are the velocity, pressure ratio and temperature ratio of the turbocharger. All of those parameters are the important parameters to determine the performance of the turbocharger compressor.

2.3. Re-design an existing driven fan for turbocharger
This is important stage where to test the performance of the proposed material of driven fan, the performance of the existing driven fan is needed to be investigated. This stage helps to check if the performance of the new design driven fan exceeds the performance of the existing one. To conduct this stage, a 3D scanner machine is prepared to be used to get accurate dimensions of the compressor wheel and will be assisted by SolidWorks software to redesign the missing surface in the 3D model due to the complexity of the compressor wheel.

2.4. Simulation
The simulation of the fluid flow on the turbocharger compressor wheel will be conducted using the SolidWorks flow simulation software. The performance of the compressor wheel with the required specification will be determined such as shape, size and material of the compressor wheel.

2.5. Design a new driven fan that made by the Polyester/Epoxy IPN for turbocharger
The new design of the turbocharger driven fan will be analyzed based on the performance of the existing compressor wheel. The new design will be improved in terms of the parameters that affecting the performance of the turbocharger. Those parameters are such as the number of blade, angle of the backswept, number of splitter blade and the material used. Then, this stage will be continued with simulation process using the SolidWorks flow simulation software.

2.6. Analysis and comparison
After the new driven fan design completed, the analysis and comparison will be performed. The new design will be accepted if the new driven fan design performance exceeds the performance of the existing fan design. Otherwise, the process will be returned to design stage. The performance refers to the ability of the turbocharger driven fan to draw ambient air into the turbocharger. The turbocharger with higher performance which is higher efficiency tends to have higher pressure ratio. This high pressure ratio produces from the high pressure outlet after being compressed in the compressor.

3. Result and Discussion
3.1. Design existing fan for turbocharger compressor

In order to get accurate dimensions of the turbocharger compressor wheel, 3D scanner machine has been used and assisted by SolidWorks software. The performance of the existing wheel can be obtained based on this important stage. Figure 2 and 3 show the completed 3D CAD model of the compressor wheel and compressor housing. Table 1 shows the related data of compressor wheel and the housing.

![Figure 2. 3D scan result of compressor wheel.](image1)

![Figure 3. Compressor housing design.](image2)

| Description                  | Data           |
|------------------------------|----------------|
| Exducer diameter             | 68 mm          |
| Inducer diameter             | 46 mm          |
| Number of blade              | 6              |
| Number of splitter blade     | 6              |
| Fan material                 | Aluminium alloy|
| Housing material             | Aluminium alloy|

3.2. Simulation for existing fan for turbocharger compressor

There are three parameters have been considered to determine the performance of the turbocharger which are pressure, velocity and temperature. The material for existing fan was made with aluminum alloy with 6 blades and 6 splitter blades. The properties of aluminum alloy are shown in Table 2.

![Table 2. Properties of aluminum alloy.](image3)

| Property              | Value       |
|-----------------------|-------------|
| Density               | 2680 kg/m³  |
| Melting temperature   | 880.38 K    |
| Conductivity type     | Isotropic   |
| Electrical conductivity| Conductor   |

3.2.1. Pressure. The higher pressure produced by the turbocharger shows that the turbocharger is more efficient. Figure 4 and 5 shows the result of simulation on the pressure inside the turbocharger. From the result it shows that the air pressure is lower at the fan and higher after discharge from the fan. The air pressure obtained at fan was about 110 kpa which is the bright green colour while the air pressure discharge from the fan was about 130 kpa which is the lighter green colour. From the results also show that the pressure increased before exiting the turbocharger.
3.2.2.  Velocity. The higher radial velocity results in stronger radial flow which will make the turbocharger more efficient. Figure 6 and 7 show the velocity contour after the simulation being done. From the results, it shows that the velocity was higher at the fan and lower after discharge from the fan. The air velocity at the fan was about 190 m/s and the air velocity that exited the turbocharger was about 30 m/s (blue colour).

3.2.3.  Temperature. Temperature is directly proportional to the pressure and volume. In this simulation the volume is constant. Figure 8 and 9 show the temperature contour of the turbocharger simulation. From the figure, it is observed that the air temperature is almost the same at all part inside the turbocharger. The temperature at the fan was just slightly higher than the temperature of air after discharge from the fan. The temperature at the fan was 360 K while the temperature after the air discharge from the fan was 340 K.
3.3. Design of driven fan that made by the Polyester/Epoxy IPN for turbocharger compressor

The design of fan that made by the Polyester/Epoxy IPN is the same as the design of the existing fan. The only different is the material used. Table 3 shows the data of the new fan design.

| Description             | Data          |
|-------------------------|---------------|
| Exducer diameter        | 68 mm         |
| Inducer diameter        | 46 mm         |
| Number of blade         | 6             |
| Number of splitter blade| 6             |
| Fan material            | Polyester/Epoxy IPN |
| Housing material        | Aluminium     |

3.4. Simulation for new fan for turbocharger compressor

SolidWorks flow simulation software is used to obtain the three parameters which are pressure, velocity and temperature. The material for new design fan was made with polymer material which is Polyester/Epoxy IPN with 6 blades and 6 splitter blades. The properties of Polyester/Epoxy IPN are shown in Table 4.

| Property                  | Value         |
|---------------------------|---------------|
| Density                   | 2680 kg/m³    |
| Melting temperature       | 880.38 K      |
| Conductivity type         | Isotropic     |
| Electrical conductivity   | Conductor     |

3.4.1. Pressure. Figure 10 and 11 shows the pressure contour of the new design of driven fan after the simulation completed. Higher pressure shows the better performance of turbocharger because more compressed air easier to burn. From the figure it shows that the pressure is lower at the fan and higher after discharge from the fan. The region with the bright green colour is the region where the pressure is lower which was 110 kPa, meanwhile the yellow colour is a region at the fan which produced high pressure at 140 kPa. The region with lighter green colour is the region with higher pressure about 130 kPa. The figure also shows that the pressure increased before exiting the turbocharger.

![Figure 10. Pressure contour in front plane.](image1)

![Figure 11. Pressure contour in top plane.](image2)
3.4.2. **Velocity.** Higher air velocity inside turbocharger produce better performance. Figure 12 and 13 shows the air velocity contour inside turbocharger obtained after simulation completed. From the figure it is found that the air velocity is higher at the fan and decreased as discharging from the fan. It can be seen as green colour region at the fan which having velocity about 190 m/s while the blue colour region is the air discharge from the fan and velocity about 30 m/s.

![Figure 12. Velocity contour in front plane.](image1)

![Figure 13. Velocity contour in top plane.](image2)

3.4.3. **Temperature.** Lower temperature is better for the performance of turbocharger compressor even though the high pressure will produce high temperature. Figure 14 and 15 shows the air temperature contour for the new design fan. From the simulation it is found that the air temperature is about the same at all part in the compressor housing. The temperature obtained from the simulation is 340 K.

![Figure 14. Temperature contour in front plane.](image3)

![Figure 15. Temperature contour in top plane.](image4)

3.5. **Analysis and comparison**

Analysis and comparison have been made in order to compare the performance of the existing and the new design of turbocharger driven fan. From the simulation, different materials of the fan affected the performance in terms of three different parameters which are pressure, velocity and temperature. Table 5 shows the simulation result between the existing fan and the new fan design.

| Design  | Existing fan | New fan design |
|---------|--------------|----------------|
|         | At fan       | Discharge from fan | At fan | Discharge from fan |
| Pressure| 110 kPa      | 130 kPa         | 140 kPa | 130 kPa         |
| Velocity| 190 m/s      | 30 m/s          | 190 m/s | 30 m/s          |
Higher air pressure inside the turbocharger produced better performance compared to lower air pressure. This is because more compress air is easier to burn inside the engine. From the results, it is found that the pressure is almost the same for the existing and new design fan. There is a slight different which is the new fan design produced higher pressure at the fan but same pressure with existing fan design when air discharge from fan. Higher air velocity will produce better performance of turbocharger. The air velocity produced by both existing and new fan design is almost the same which was about 30 m/s. However, there is only slight different as shown in Figure 6 and 12 which indicated that the velocity is higher for the new fan design. The temperature has been compared in terms of the air temperature inside the compressor housing for the existing and new fan design. As illustrated in Figure 9 and 15, it was found that the temperature was the same after air discharge from the fan. The new fan design produced lower temperature at the fan compared to the existing fan as shown in Table 5.

4. Conclusion
This study is about the development of turbocharger compressor driven fan for passenger car. The new fan design would be able to increase the turbocharger performance. In this study, the performance is determined based on the three important parameters which are pressure, velocity and temperature inside the turbocharger compressor. Simulation has been conducted on the existing and the new fan design in order to analyze and make a comparison on the performance of these two different fans. Good performance of turbocharger should have high pressure, high velocity and low temperature inside the turbocharger compressor. For the existing fan design, the 3D scanner machine and SolidWorks software have been used. The material used was aluminum alloy which having density of 2680 kg/m3. The results for the simulation was 130 kPa for pressure, 30 m/s for velocity and 340 K for temperature inside the turbocharger compressor when the air discharge from the fan. The results show different value at the fan which is 110 kPa for pressure, 190 m/s for velocity and 360 K for temperature. Meanwhile, for the new fan design, the design was the same with the existing fan but the material was replaced. The material used for the new fan is Polyester/Epoxy IPN. Polyester/Epoxy IPN is used because of its advantages compared to aluminum alloy. One of the advantages is the material is cheaper than aluminum alloy. The manufacturing process of Polyester/Epoxy IPN is also easier that using casting process compared to aluminum alloy fan which is produced by machining process where costly. The simulation was completed and the results obtained were the same with the simulation result of the existing fan design when air discharge from fan. However, the results were different for the value obtained at the fan which were 140 kPa for pressure, 190 m/s for velocity and 340 K for temperature. This shows that the air pressure of the fan that made by the Polyester/Epoxy IPN increased, but decreasing the air temperature inside the turbocharger compressor.

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References
[1] Miller J K 2008 Turbo: Real World High-Performance Turbocharger Systems. CarTech Inc.
[2] Rajoo S 2008 Automotive Turbocharging. Johor Bahru: Penerbit Universiti Teknologi Malaysia
[3] Zheng X, Sun Z, Kawakubo T and Tamaki H 2017 Experimental investigation of surge and stall in a turbocharger centrifugal compressor with a vaned diffuser Experimental Thermal and Fluid Science 82 493-506
[4] Zhu S, Deng K and Liu S 2015 Energy, Modelling and extrapolating mass flow characteristics of a radial turbocharger turbine 628-637
[5] Liu S, Liu C, Hu Y, Gao S, Wang Y, and Zhang H 2016 Fatigue life assessment of centrifugal compressor impeller based on FEA Engineering Failure Analysis 60 383-390
