COMPUTATIONAL APPROACH TO IMPROVE THE PERFORMANCE OF THE AIR-TURBINE WITH DIFFERENT TYPE IMPELLER BLADES FOR THE DENTAL HANDPIECE

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Abstract— The high-speed dental air-turbine handpiece is widely used in cutting and polishing denture structure in dentistry. The handpiece has the air-turbine which rotates a cutting bur. The air-turbine impeller is rotated by the compressed-air. There are different blade types for the impeller such as flat, concave and gull. The gull and concave type impeller blades were selected for the air-turbine. The objective of the study was to investigate the flowfield of the air-turbine with the gull and concave types impeller blade and to compare the results. The computational domain of the air-turbine was computed usingANSYS CFX Computational Fluid Dynamics (CFD) software. The air-turbine with the concave and gull type impeller blade was analyzed and the results were evaluated by the velocity, pressure and the torque. The air-turbine with the concave type impeller blade had higher torque value than the air-turbine with the gull type impeller blade.

Keywords— CFD, concave type blade, gull type blade, impeller, ANSYS CFX, immersed solid.

I. INTRODUCTION

High-speed dental handpiece which has air-turbine was introduced as a dental cutting tool in 1957. The dental handpiece are widely used in almost all dental cares such as drilling and cutting teeth and a tooth extraction [1, 2]. Common dental handpiece consist a head which cuts the tooth, air inlet which supplies the compressed-air and connector which connects the head and the air-inlet. There are optic and non-optic dental handpieces which lighten the visual field of the treatment area of the tooth. The head, the length of the body, coupling, size and shape of the handpieces are all different by the manufacturer. The compressed-air from the air inlet pushes the air-turbine impeller blade, applies pressure to the blade and the air-turbine rotates cutting bur and bur cuts the tooth. The air-turbine rotated by the compressed-air about a 250.000 ~ 400.000 revolutions per minute (RPM) range and it called the high-speed dental handpiece [3, 4].

The air-turbine handpieces were studied numerically and experimentally with different impeller blade number and blade shape. The torque value increased as the angle of reflection increased while the torque value decreased as the number of the blade increased [5-7]. The back airflow was reduced as distance between air-inlet and air outlet increases. The back airflow inside the head was the factor to increase the noise and to reduce the rotational force. There were different variables which influence the performance of the dental handpiece such as the torque affects the vibration of the dental handpiece [8]. The performance of the air-turbine was investigated by changing the angle and tip width of the rotor blades and the results were evaluated by the torque. The design parameters influencing the performance of the dental handpiece air-turbine was studied [9]. The design variables were tip width and blade angle, respectively.

The objective of the study was to investigate the air-turbine with the concave and gull type impeller blade and to compare the results. The air-turbine with the developed concave and gull type impeller blade was computed using ANSYS CFX software [10]. The computed results were evaluated by the velocity, pressure and the torque. The torque value was high when the air-turbine with concave type impeller blade is computed.

II. COMPUTATIONAL PROCEDURE

2.1. Computational tools and turbulence model

ANSYS CFX software consists of Design modeler, CFX-Pre, CFX-Solver and CFX-Post. The ANSYS Design modeler provides the geometry, modifies the geometry read-through data formats while ANSYS CFD-Post allows performing advanced quantitative analysis and creating high-quality visualizations. Computational Fluid Dynamics (CFD) simulation helps to predict fluid flows and to design new equipment for manufacturing [11]. CFD solve Reynolds-averaged Navier-Stokes equations using turbulence models to compute the averaged turbulent stresses. The turbulence models often limit the accuracy of CFD simulations. Standard two-equation turbulence models often fail to predict the onset and the amount of flow separation under adverse pressure-gradient conditions. k-ε turbulence model was used for the computation. However, the turbulence models were designed to make highly accurate predictions of the onset and amount of flow separation under adverse pressure gradients by the inclusion of transport effects into the formulation of the eddy-viscosity [12].

2.2. The computational domain of the air-turbine

The compressed-air which rotates the air-turbine exhausts through outlet, driving the air-turbine by using the power of the air-turbine bucket. The compressed-air passes through the gap between the impeller and shroud of the cartridge, flows through the inlet of the connecting load and rotates the air-turbine. The computational domain of the air-turbine had the air inlet, air outlet, impeller and housing. The domain of the air-turbine was divided into two domains such as fluid and immersed solid domain. Figure 1 shows thedental handpiece and computational domain of the air-turbine with the gull type impeller blade. The handpiece is largely divided into three parts head, neck and body parts. The impeller was immersed solid domain while the other parts are the fluid domain. The developed gull type and concave type impeller blades were selected for the computation. The dimensions of the air-turbine computational domain are given in Table 1. The inner and outer radii of the blades were 3.5 mm and 5.65 mm, respectively. The angle of the impeller blades was 90° and the gap (or tip clearance) between the housing/shroud and the tip of the impeller blade was 0.2 mm. The gull and concave type impellers have eight blades. The height of the impeller blade was 3.1 mm. The length of the air inlet was 70mm and the air inlet tube has inclination at the 15 mm before connecting the housing. The neck was designed to prevent slipping. The areas of the air inlet and the air outlet were 3.14 mm^2 and 7.65 mm^2, respectively.

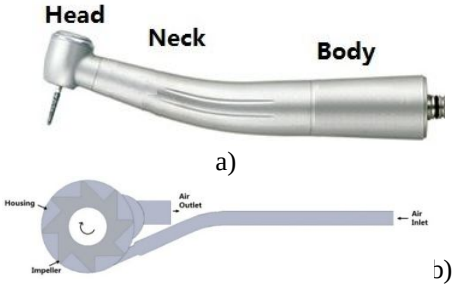


Fig. 1. The dental handpiece a) and computational domain of the air-turbine (top view) b)

Table 1.Dimensions of the impeller and housing for the computation

Dimensions of impeller	
Inner radius, mm	3.5
Blade Angle, ^{0}	90
Outer radius, mm	5.65
Gap, mm	0.2
Height, mm	3.1
Blade piece	8
Dimensions of the housing, air inlet and air outlet	**Value**
Housing height,mm	4.75
Housing diameter, mm	11.56
Air inlet area, mm^2	3.14
Air inlet length, mm	70
Air outlet area, mm^2	7.65

2.3The boundary conditions and the grid validations for the computational domain

The working fluid was an air under atmospheric pressure condition and the reference temperature of the air was 25°C. The wall boundary condition was used for the housing wall and the impeller blades. All walls of the domain were treated as viscous adiabatic surfaces with a no-slip velocity condition. Table 2 presents the boundary conditions which are used for the computational domain. The pressure condition of 3 bar was at the air inlet of the computational domain. The outlet condition was applied at the air outlet while the relative pressure was zero atmospheric pressure. The air-turbine computational domain was analyzed by transient analysis. The air inlet, air outlet and housing of the fluid domain were fixed. The immersed solid domain (impeller) rotates with 300.000RPM angular velocity. The total time and time steps were 0.001s and 5.5556E-7 s (1/360°), respectively. The computational results were obtained using parallel computers running on a Linux operating system. The grid of the computational domain was generated by hex grid and the hex dominant meshing is applicable to small domains. The grid validation study was performed to ensure that the computed quantities would properly converge. Table 3 presents the grid validation results by the grid elements with the torque of the air-turbine. The numbers of the grid elements were between 1.5 million – 4.5 million. The grid validation indicated that the proper number of grid elements was about 3.2 million, while the maximum and minimum element sizes were 0.0005 m and 0.0001 m, respectively.

Table 2. The boundary conditions for the computational domain

Boundary Conditions	**locations**	**Value**
Inlet	Air inlet	3bar
Outlet	Air Outlet	OPa
Wall	Housing	No slip, adiabatic

Table 3. Grid generation test: grid element number vs. torque

Grid Elements, million	**Torque, Nm**
1,5	0.002822
2,0	0.003015
2,5	0.002896
2,9	0.002886
3,2	0.002888
3,7	0.002885
4,1	0.002886
4,5	0.002885

III. RESULTS AND DISCUSSION

3.1. The concave type impeller blades of the air-turbine

The computational domain of the air-turbine with the gull type and concave type impeller blade was

analyzed to determine the effect of the impeller type for the performance of the air-turbine. The gull type and concave type impeller blades were selected to compute the air-turbine computational domain. The air-turbine with the concave type impeller blade was computed by given boundary and solver conditions. The compressed-air from the air inlet rotated impeller and flowed out through the air outlet. The impeller is the main part of the air-turbine and rotated by the compressed-air supplied through the air inlet of the air-turbine. Figure 2 shows the velocityand pressure distributions of the computational domain of the air-turbine with the concave type impeller blade. The compressed-air from the air inlet pushed the center part of the front surface of the impeller blade and passes through the gap between the impeller blade and shroud of the turbine cartridge and exhausts through the air outlet. Most part of the compressed-air from the air inlet pushed the impeller blade while the other part of the air passes through the gap and pushes the front surface of the next blade. The compressed-air from the air inlet is non-uniform due to neck angle of the inlet tube. The airflow accelerates at the neck part of the air inlet tube. The rotating speed of the impeller was 300.000RPM. The periodic cycles achieved after about 270^o at the intervals of 45^o. The number of the impeller blades was eight and there were eight repeated intervals as shown in Figure 3. The impeller of the air-turbine was rotated one full revolution from 360^o. The maximum torque value at the repeated intervals was 0.002474 Nm.

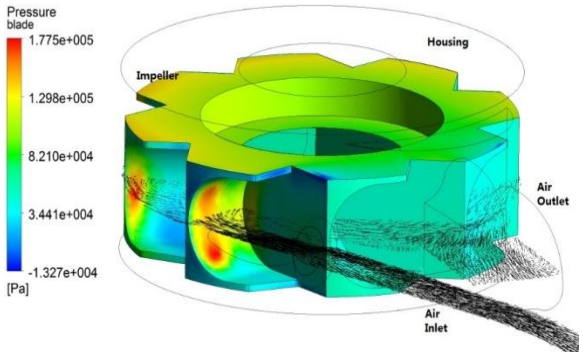


Fig.2. The pressure and velocity distributions of the air-turbine computational domain

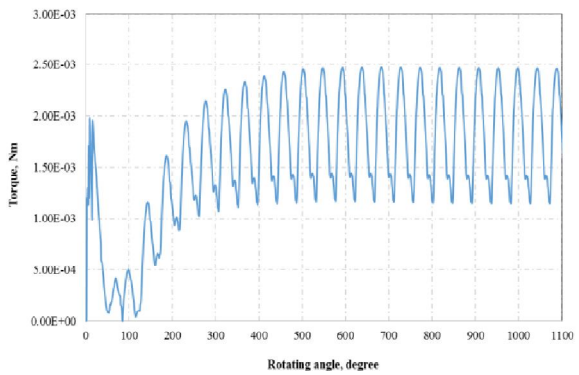
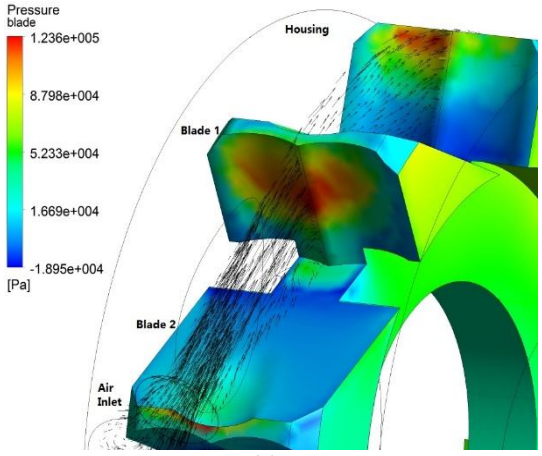


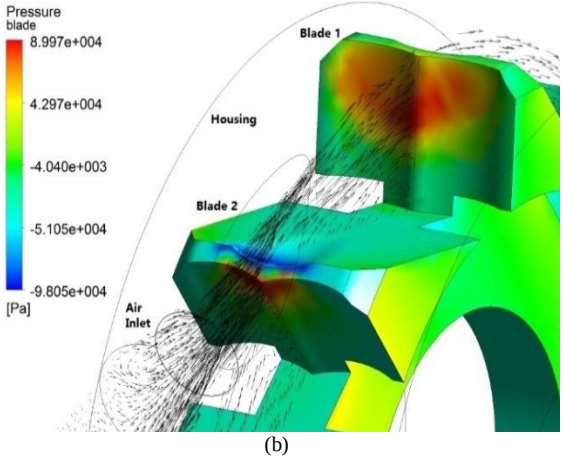
Fig.3. The torque value with rotating angle

3.2. The gull type impeller blades of the air-turbine

The computational domain of the air-turbine with the gull type impeller blade was computed under the same the boundary and solver conditions. The air pressure at the impeller blades and velocity distributions are shown in Figure 4. The compressed-air from the air inlet hits the blade 1 mostly and relatively small portion of the compressed-air hits the blade 2 and blade 8 when the rotating angle was 20^o. The pressure distributions at the blades varied significantly depending on the blade position with respect to air inlet entrance. The compressed-air from the air inlet divided into two portion due to the position of the blade at the air inlet entrance, one portion of the air bumped at the surface of the impeller blade 2 and other portion of the air hits the blade 1 and flows through the gap. The compressed-air from the air inlet hits the front surface of the blade 1 and the vortex was formed at the rear surface of the blade 2. The air pressure was applied in the opposite direction of the rotation and it decreases torque when the rotating angle was 35^o. The maximum torque value was obtained when the direction of the compressed-air from the air inlet was perpendicular to the blade angle. The maximum and minimum torque values at the repeated intervals were 0.002353Nm and 0.000138Nm, respectively.



(a)



(b)

Fig.4. The pressure and velocity distributions of the computational domain a) 20^o and b) 35^o

3.3 The comparing gull type and concave type impeller blades of the air-turbine

The computational results of the air-turbine with the gull type and concave type impeller blade were compared to analyze the effect of the impeller type. The gull type and concave type impeller blades were computed under the same conditions while the height and radii of the impeller blades were same. The results of the air-turbine computational domain were presented with gull type and concave type impeller blades in previous sections. The computational results were evaluated by the torque, pressure and velocity. Among them most important value to determine the performance of the air-turbine was the torque. The torque affects the vibration of the handpiece and the cutting capability of the actual tooth and affects the oscillation amplitude of the handpiece vibration and improves the cutting capability when the average torque value is high. Figure 5 shows the torque values for the one cycle of the gull type and concave type impeller blades. The torque value was high with the concave type impeller blade. The air pressure distribution at the blade was different depending on the blade shape. Figure 6 shows the pressure and velocity distributions for the air-turbine with gull type impeller blade. The compressed-air from the air inlet hits the center of the impeller blade for the concave type impeller blade. The area of the air pressure at the blades are scattered for the gull type impeller blade due to the shape of the blade. The gull type impeller blade required some more improvements to increase the torque. The concave type impeller blade will be next study to investigate for the optimization design of the air-turbine.

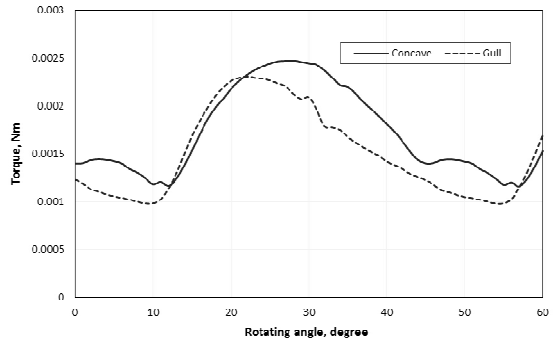


Fig.5. The torque value with rotating angle with gull type and concave type impeller blades

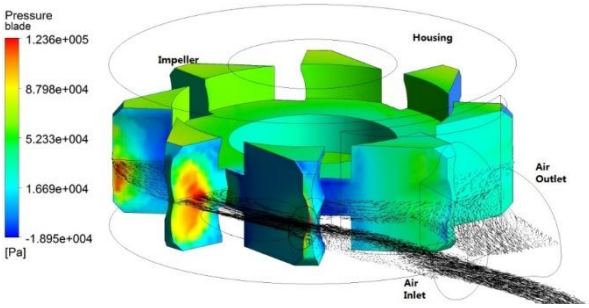


Fig.6. The pressure and velocity distributions of the air-turbine domain with gull type impeller blade

CONCLUSIONS

The high-speed dental handpiece air-turbine with the gull type and concave type impeller blades was investigated to determine the effect of the blade type for the air-turbine performance. The gull type and concave type impeller blades were selected for the air-turbine. The computational domain of the air-turbine was computed usingANSYS CFX software. The fluid domain was fixed while the impeller (immersed solid domain) was rotated with 300.000RPM angular velocity. The total time and time steps were 0.001s and 5.5556E-7 s (1/360°), respectively. The inner and outer radii of the gull type and concave type impeller blades were 3.5 mm and 5.65 mm, respectively while the height of the blades was 3.1 mm. The computational results of the air-turbine were evaluated by the torque, pressure and velocity. The torque value of the air-turbine with concave type impeller blade was higher than the gull type impeller blade. The maximum torque values of the gull type and concave type impeller blades were 0.002353 Nm and 0.002474 Nm, respectively. The gull type impeller blade for the air-turbine was required some more improvements and the concave type impeller blade was selected for the air-turbine optimization design study.

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