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COMPUTATIONAL APPROACH TO IMPROVE THE PERFORMANCE OF THE AIR-TURBINE WITH GULL TYPE IMPELLER BLADE FOR THE HIGH-SPEED DENTAL HANDPIECE

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Abstract— The high-speed dental handpieceair-turbine is widely used in cutting and polishing denture structure in dentistry. The impeller of the air-turbine is the important part of the dental handpiece. The objective of the study was to investigate the flowfield of the air-turbine with the gull type impeller and to find the design variables for the optimization. The flowfield of the air-turbine was computed usingANSYS Fluent Computational Fluid Dynamics (CFD) software. The airflow inside the air-turbine was analyzed by changing the height and number of the impeller blade and location of the air inlet. The computed results were evaluated by the velocity, pressure and the torque. The torque value was increased when the height of the blade and connecting location of the air-inlet are changed.

Keywords— CFD, Gull Type Impeller, Fluent, Moving Wall.

I. INTRODUCTION

High-speed dental handpieces are used as a dental cutting tool during dental procedures, and to remove decay and shape tooth to the insertion of a filling or crown. The dental handpiece has air-turbine which rotates at speed of 300.000 to 400.000 revolutions per minute (RPM). The air-turbine uses the compressed-air to rotate a cutting bur [1, 2]. The rotating component of the air-turbine is impeller.

The air-turbines were analyzed numerically and experimentally with different impeller blade shapes [3-5]. There were different variables which influences the performance of the dental handpiece, i.e., such as the torque affects the vibration of the dental handpiece [6]. The performance of the air-turbine was investigated by changing the angle and tip width of the rotor blades. The design parameters influencing the performance of the dental handpiece air-turbine, i.e., torque was studied and the design variables were tip width and blade angle, respectively [7].

The objective of the study was to investigate the flowfield of the air-turbine and to find the influential design variables for the optimization. The air-turbine with the developed gull type impeller was computed using ANSYS Fluent software. The air-turbine flowfield was analyzed by changing the height and number of the impeller blade and location of the air-inlet. The torque was computed with the rotational speed of 300,000 RPM. Reducing the height of the impeller blade and changing air-inlet connection influenced the torque value of the air-turbine significantly.

II. ANALYSIS

2.1. The computational domain of the air-turbine

The impellers of the air-turbine are driven by the compressed-air from the air-inlet. Supplied high-pressure compressed-air passes through the gap between the impeller and shroud, and rotates the air-turbine impeller. The compressed-air exhausts through outlet after driving the air-turbine by using the power of the air-turbine bucket. Figure 1 shows the computational fluid domain of the air-turbine and gull type impeller blade. The computational domain had the air inlet, air outlet and housing. The impeller of the air-turbine was subtracted from the housing for the computation. The high-pressure compressed-air enters through the air inlet, strikes the turbine impellers and flows out through the air outlet.

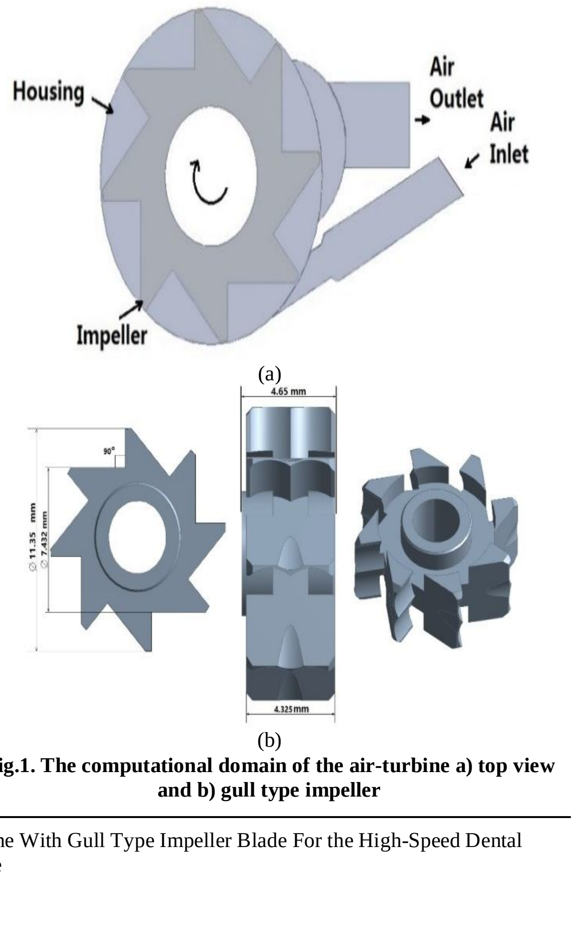


Fig.1. The computational domain of the air-turbine a) top view and b) gull type impeller

2.2. The computational procedure

The flowfield of computational domain was turbulent flow of an air. The domain was computed by the k-ε turbulent model of ANSYS Fluent [8]. Computational Fluid Dynamics (CFD) simulation software helps to predict fluid flows and to design new air-turbine for manufacturing [9]. ANSYS Fluent contains physical modelling options, turbulence, heat transfer and reactions for industrial applications. ANSYS CFD-Post allows performing advanced quantitative analysis and creating high-quality flowfield visualizations.

CFD solves 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 [10].

2.2.2 The boundary conditions and the grid validations study

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. The boundary conditions were applied for the computational domain as given in Table 1. The inlet gage pressure condition of 300,000Pa was applied at the air inlet. The outlet condition was applied at the air outlet while the relative pressure was zero atmospheric pressure. The computational domain was analyzed by steady state condition. The air inlet, air outlet and housing of the domain were fixed. The impeller of the air-turbine in the computational domain was rotated with specified angular velocity about the given axis to simulate the impeller. The moving wall option was applied to the impeller wall. The wall option enables specification of the tangential wall motion. The computational domain of the air-turbine was single domain. 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 element size was 0.00025m for this domain to create well shaped hexes. The grid validation study was performed to ensure that the computed quantities would properly converge. Table 2 presents the grid validation results by using the torque of the air-turbine. The numbers of the grid elements were between 0.7 million – 2.4 million. The grid validation indicated that the proper number of grid elements was about 1.9 million, while the maximum and minimum element sizes were 0.00025 m and 0.0001 m, respectively.

Table 1: The boundary conditions for the computational domain

Boundary Conditions	locations	Value
Inlet	Air inlet	300000 Pa
Outlet	Air Outlet	0 Pa
Wall	Housing	No-slip, adiabatic
Moving wall	Impeller	300.000RPM, Moving wall,

Table 2: Grid generation test: grid element number vs. torque

Grid element number, million	Torque, Nm
0.7	0.002181
0.9	0.002185
1	0.00221
1.3	0.002215
1.5	0.00225
1.7	0.002312
1.9	0.002319
2	0.0023195
2.2	0.002318
2.4	0.002319

III. RESULTS AND DISCUSSION

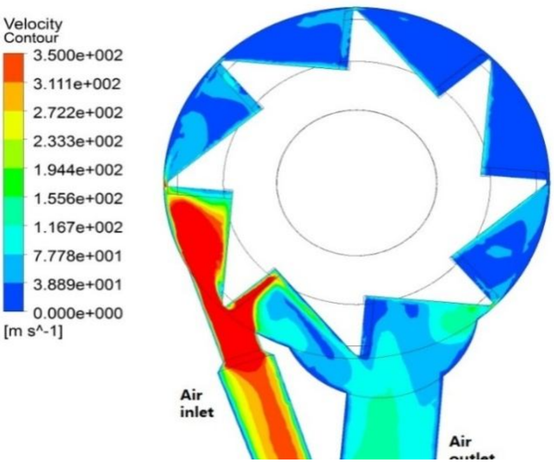
3.1Analyzing the air-turbine with the gull type impeller blade

The impeller is the main part of the air-turbine and is rotated by the compressed-air supplied through the air inlet. The compressed-air passes through the gap between the impeller blade and shroud of the turbine cartridge and exhausts through the air outlet. The flowfield of the air-turbine with the gull type impeller blade was investigated. The dimensions of the air-turbine impeller blade are given in Table 3. The inner and outer radii of the blades were 3.716 mm and 5.675 mm as shown in Figure 1, 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 height of the impeller blade was 4.325 mm.

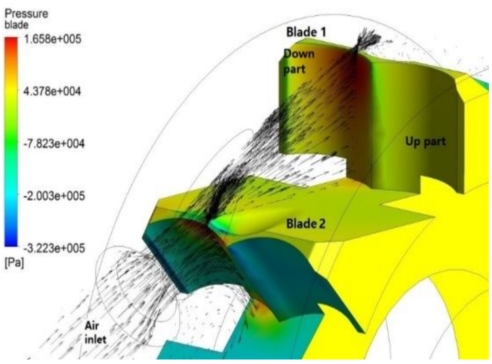
Figure 2 shows a) the velocity and b) pressure distributions in the computational domain. The airflow affected the front and rear surfaces of the impeller blades. Most part of the airflow from the air inlet pushed the down part of the impeller blade 1 while the other part of the airflow pushed the front and rear surface of the blade 2. The most of the airflow from the air inlet bumped against the impeller blade 2, and the loss incurred which resulted in the minimum torque value. The pressure was applied in the opposite direction of the rotation and thus it resulted in the low torque. The maximum torque value at the impeller blades was 0.002319 Nm. The rotational speed of the impeller was 300,000 RPM and the number of the impeller blade were eight.

Table 3: Dimensions of the impeller and housing for the computation

Dimensions of impeller	Values
Inner radius, mm	3.716
Blade Angle, ^{0}	90
Outer radius, mm	5.675
Gap, mm	0.2
Height, mm	4.325
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 outlet area, mm^2	7.65



(a)



(b)

Fig.2. a) The velocity b) pressure distributions at the computational domain

3.2. Influence of impeller blade number

The influence of the impeller blade number on the torque was investigated with different impeller blade numbers. The impeller blades were seven and nine, and other dimensions were the same as presented in Table 3. Most part of the airflow from the air inlet pushed the front surface of the impeller blade 1 when the impeller has seven and nine blades as shown in Figure 3. The airflow affected the front and rear surfaces of the blades when the impeller had eight blades as shown in Figure 2 a). The airflow from the air inlet was divided into two branches due to the position of the blade at the air inlet entrance. Figure 3 c) shows the pressure distributions at the blade 1 with the velocity distributions. All airflow 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. Table 4 shows the torque value with different blade pieces. The relatively highest torque value was 0.002319 Nm when the impeller has eight blades. The air inlet was connected to the housing that the compressed air hits at the down part of the impeller blade. The compressed-air from the air inlet hits the down part of the blade as shown in Figures 2b) and 3c). Figure 4 b) shows the possible connections of the air inlet to the housing.

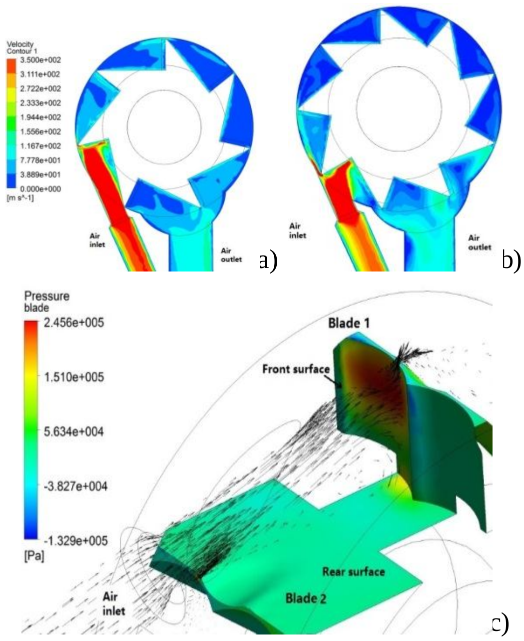


Figure 3. The velocity distributions with a) seven blades and b) nine blades (horizontal cut view at the air-inlet center) and c) the pressure distributions at the blade 1 when the impeller has seven blades

3.3 Influences of the air inlet location on the torque

The air inlet location was changed so that the compressed-air from the air inlet can push the center and up part of the impeller blade. The all dimensions of the air-turbine computational domain were the same. The pressure distributions at the impeller blades were different depending on impeller blade positions. The compressed-air from the air inlet pushed the center part of the impeller blade. The air inlet was connected to the housing so that the airflow hits at the center of the impeller blade. The compressed-air from the air inlet hits the center part of the front surface of the blade 1 as shown in Figure 4 a). The air from the air-inlet affected the rear surface of the impeller blade 2 through the vortex flow. The relatively highest torque value of 0.002570 Nm was obtained when the compressed air hits at the center part of the impeller blade.

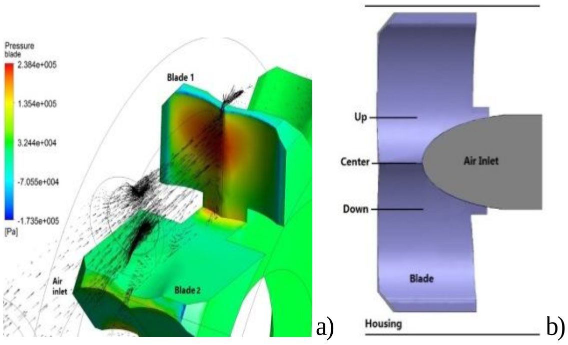


Fig.4. The pressure and velocity distributions when a) the air inlet in the center of the blade and b) air inlet locations

3.4 Influences of the impeller blade height on the torque

Some cases changing impeller is more comfortable than the changing air-inlet location. The height, inner and outer dimensions were reduced. The dimensions of the reduced impeller blade are given in Table 5 while Table 3 shows the original dimension. The inner and outer radii of the blades were 3.5 mm and 5.65mm, respectively. The gap was slightly increased. The height of the impeller blade was 3.1 mm while the air inlet location and the other dimensions were the same. The pressure distributions at the impeller blades were similar even though the air inlet changed to the center as shown in Figure 4 a). The compressed-air from the air inlet pushed the center part of the blade when the height of the impeller blade was reduced. Table 6 presents the torque value with different cases. The similar torque value was obtained when the impeller blade height is reduced and the air-inlet location is changed such as 0.002500 Nm and 0.002570 Nm, respectively.

Table 5: Dimensions of the reduced impeller blade and housing

Dimensions of impeller	Values
Inner radius, mm	3.5
Blade Angle, ^{0}	90
Outer radius, mm	5.65
Gap, mm	0.225
Height, mm	3.1
Housing height, mm	4.75

Table 6: The torque values for the different cases

Cases	Torque, Nm
8 blades	0.002319
Reduced size blade	0.002500
Air-inlet at the center	0.002570

CONCLUSIONS

The high-speed dental air-turbine handpiece was analyzed in this study using ANSYS Fluent software. The computational domain of the air-turbine of the handpiece has the impeller, air inlet, air outlet and housing. The impeller is main part for the air-turbine of the dental handpiece. The gull type impeller blade was selected for the impeller to improve the performance of the torque. The air-turbine with the gull type impeller blade was analyzed to find the design variables for the optimization. The influence of the gull type impeller blade on the torque was computed by changing the impeller blade number, by reducing the impeller blade height and by changing location of the air-inlet. The inner and outer radii of the gull type impeller blade were 3.716 mm and 5.675 mm, respectively, while the height of the blade was 4.325 mm. The computed results were evaluated by the torque, pressure and velocity.

The influence of the impeller blade number on the torque was investigated with seven, eight and nine impeller blades. The relatively highest torque value was 0.002319 Nm when the impeller has eight blades. The air inlet location was changed so that the compressed-air from can push the center part of the impeller blade. The maximum torque value of 0.002570 Nm was obtained when the compressed air hits at the center part of the impeller blade. The height, inner and outer dimension of the blade were reduced. The compressed-air from the air inlet pushed the center part of the blade. The similar torque was obtained when the impeller blade height is reduced and the air-inlet location is changed such as 0.002500 Nm and 0.002570 Nm, respectively. The height of the blade and location of the air-inlet were more significant design variables due to the torque.

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