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2004년 유체기계공업학회 학술발표회(12.3 -12.4)

박용 터보챠저 압축기의 임펠러 출구지름 변경에 따른 유동 해석연구

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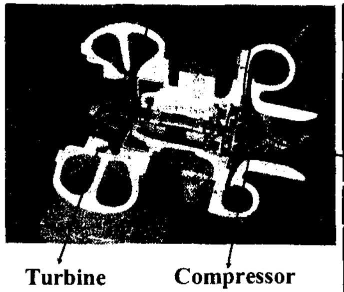
1. Introduction

Typical turbocharger cross section



Focus

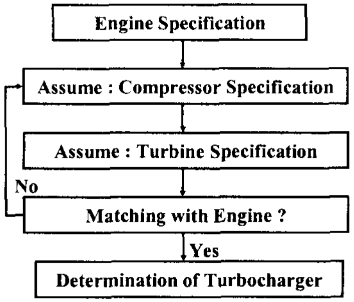
I. Simple and Quick Preliminary Design
1) Mean-Line Design Method by Using Variable Slip factor
2) 3-dimensional Design : Bezier-Polynomial Equation

II. 3-dimensional Flow Analysis

III. Blade Exit Diameter Variation
How Much have been increased?
1) Mass Flow Rates
2) Compression ratio

1-1) Turbocharger Matching & Design Point

Turbocharger Matching With Engine



Engine Specification
Assume : Compressor Specification
Assume : Turbine Specification
Matching with Engine ?
No
Yes
Determination of Turbocharger

Design Point

Mass Flow Rate	1.25 kg/s
Compression Ratio	4.0
Revolution	54407 RPM
Efficiency	80 %

Engine Power	900 kW

2. Quasi 2D & 3D Design for Compressor

Given : mass flow rate, compression ratio, efficiency, revolution

Inducer design : to satisfy minimum relative Mach No. at tip radius

Impeller exit diameter and width design

$$Real\_Work = \frac{Ideal\_Work}{Efficiency}$$

$$\lambda = \frac{C_{t2}}{C_{m2}}$$

$$\mu = \sigma \times \lambda \big/ (\lambda - tan(\beta_{2b}))$$

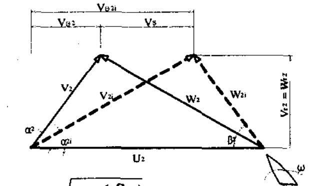
$$U_2 = \sqrt{(Real\_Work) \big/ \mu}$$

$$D_2 = 60 \times U_2 \big/ \pi N$$

Ct_2 : Impeller exit tangential velocity
Cm_2 : Impeller exit radial velocity
σ : Slip factor
U_2 : Impeller exit circumferential velocity
D_2 : Impeller exit diameter

2-1) Comparison Between Constant & Variable Slip Factor

Slip factor setup is very significant on design stage for centrifugal compressor



Slip Velocity

$$V_s = U(1-\sigma)$$

$$\sigma_1 = 1 - \frac{\sqrt{cos(\beta_2)}}{Z_r^{0.7}}$$

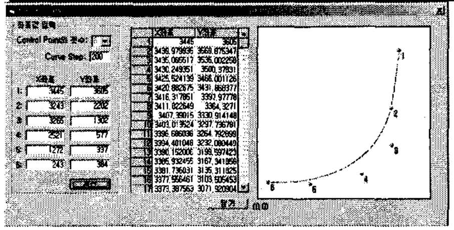
$$\sigma_2 = 1-(1+\phi_2 cot(\beta_2))\left[1-\left\{1+\frac{B_2^{0.35}\times DR\times\pi sin(\beta_2)}{2Z_r\left(1-\frac{r_{1m}}{r_2}\right)}\right\}^{-1}\right]$$

σ1 (Wiesner's equation)
: Function of simple geometry
(exit angle, blade number)

σ2 (Oh's equation)
: Function of flow coefficient and geometry
(exit angle, blade number, velocity, mass)

2-2) Three Dimensional Geometry Design

Meridional Plane Design Approach with Bezier Polynomial



1:	3445	3605
2:	3243	2202
3:	3265	1302
4:	2521	577
5:	1272	337
6:	243	384

1	3445	3605
2	3439.979935	3569.875347
3	3435.069517	3535.002258
4	3430.249351	3500.37831
5	3425.524139	3466.001126
6	3420.882675	3431.868377
7	3416.317851	3397.97778
8	3411.822649	3364.3271
9	3407.39015	3330.914148
10	3403.013524	3297.736781
11	3398.686036	3264.792899
12	3394.401048	3232.080449
13	3390.152006	3199.597423
14	3385.932455	3167.341856
15	3381.736031	3135.311825
16	3377.556461	3103.505453
17	3373.387563	3071.920904

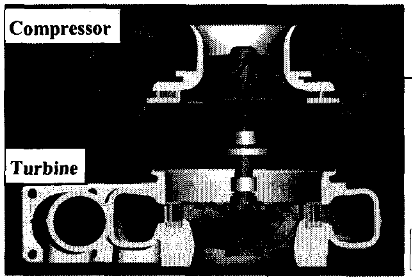
Hub camber line
R(z)=555.604+10.4775 • Z+0.0706825 • Z^2+0.00016107 • Z^3
θ(z)=266.635+7.10439 • Z+0.0596691 • Z^2+0.000150585 • Z^3

Shroud camber line
R(z)=704.773+13.3984 • Z+0.0965393 • Z^2+0.000231222 • Z^3
θ(z)=292.836+7.35392 • Z+0.0588548 • Z^2+0.00014109 • Z^3

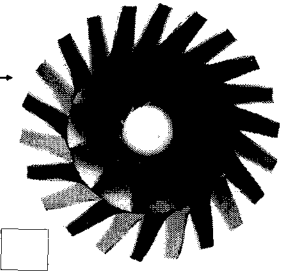
Diffuser Design → K & Cp Setup → NACA 65 -2-10

2-3) Generated Three Dimensional Geometry Design

Side View of Turbocharger



Front View of Compressor



3. Three Dimensional Flow Analyses

Governing Equation & Boundary Condition

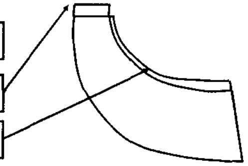
Governing Equations		Continuity Equation
		Momentum Equation
		Energy Equation
		Standard κ-ε Equation
Boundary Conditions	Inlet Pressure	101,325 Pa
	Exit Pressure	280,000 Pa
	Inlet Temperature	25 °C
	Revolution	54407 RPM
	Wall	Adiabatic

3-1) Comparison Between Flow Analysis and Experiment

	Experiment (similar to design)	Design Analysis	Deviation
Compression Ratio	4.006	4.34	7.7 % +
Mass Flow rates (kg/s)	1.3226	1.2626	4.54 % +
Efficiency(%)	77.04	83.25	6.21 % +

Design Approach(3 Method) :

Increasing Mass Flow Rates and Compression Ratio



1) Higher RPM

2) Higher Exit Diameter

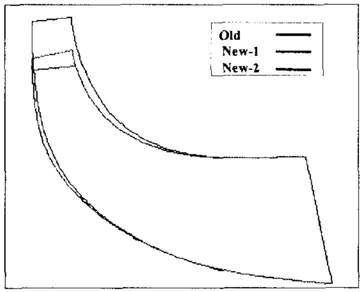
3) Higher Shroud Diameter

3-2) Impeller Exit Diameter Variation Design

Unit : mm, degree, ea

Component	Each Part	Old	New-1	New-2
Impeller	Hub Diameter	37.8	37.8	37.8
	Tip Diameter	112.4	112.4	112.4
	Exit Diameter	166	174	195
	Inlet Angle	51.7	51.7	51.7
	Exit Angle	69.1	69.1	69.1
	Blade Number (ea)	22	22	22
	Exit Width	7.92	7.92	7.92
Diffuser	Inlet Diameter	202.4		
	Exit Diameter	252.9		
	Inlet Angle	20.7		
	Exit angle	31.5		
	Blade Number	17		

3-3) Comparison of Three Different Geometry



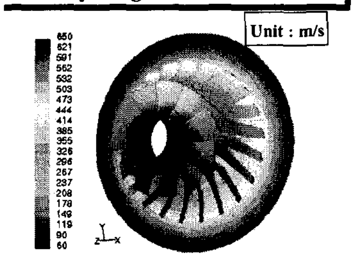
3-4) Comparison of Analysis Results

	Old	New-1	New-2
Exit total Pressure (Pa)	381706	420037	490255
Compression ratio	3.77	4.15	4.83
Compression ratio rise	-	10.08 % (+)	28.12 % (+)
Mass flow rates (kg/s)	1.21	1.54	1.36
Mass flow rates rise	-	27.3 % (+)	12.4 % (+)
Exit total temperature (K)	474.4	469.8	519
Efficiency (%)	77.89	87.02	76.62
Inlet Mach number	0.36	0.48	0.47
Exit Mach number	0.68	1.07	1.22

4. Flow Patterns - Old

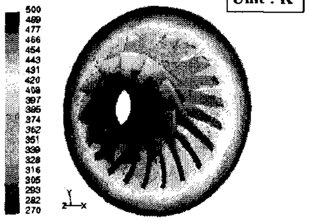
Velocity Magnitude Distribution

Unit : m/s



Static Temperature Distribution

Unit : K



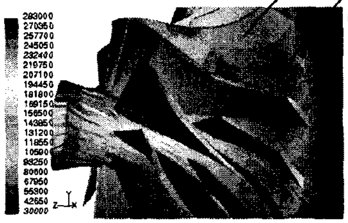
- Absolute velocity magnitude and temperature rise is stable.

4-1) Comparison of Static Pressure Contours

Old

Full Blade

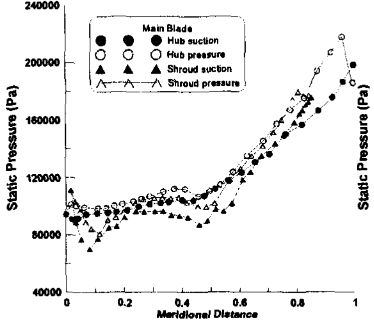
Splitter Blade



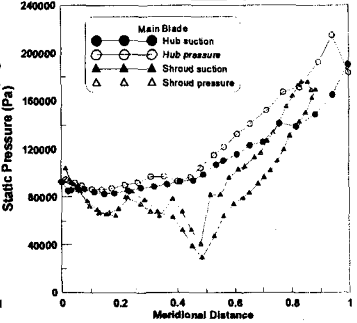
New

4-2) Load Distribution of Full Blade

Old

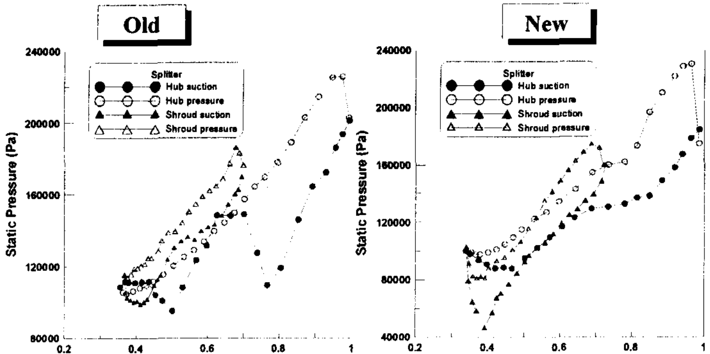


New



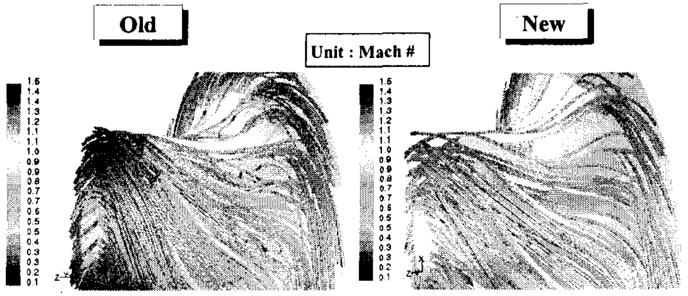
- Flow choking phenomenon is observed at inlet on the old impeller while it occurs at the mid in new impeller case.

4-3) Load Distribution of Splitter Blade



- Pressure decrease suddenly and increase at 80 % of hub suction side in design impeller.

4-4) Comparison of Flow Path Lines



- Flow circulation has been happened at the interior of old impeller.
- Flow path lines of new impeller are more smooth than that of design impeller.

5. Conclusion

1. A simple and quick design approach for compressor has been established by turbocharger matching and aerodynamic preliminary design.

2. Three dimensional flow analysis results was very similar to experimental data under 2.0% deviation error.

3. Compressed mass flow rates of new impeller whose exit diameter is simply 8mm longer than old has been 27.3% higher than that of old impeller. And compression ratio was 2.7% higher than old one.

4. From these design and analysis results, the same compressor casing can be used at each different impeller geometry efficiently. Another casing manufacturing is not necessary.