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INFLUENCE OF THE VOLUTE DESIGN PARAMETERS ON THE PERFORMANCE OF A CENTRIFUGAL COMPRESSOR OF AN AIRCRAFT TURBOCHAGER

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Theoretical and experimental study on the effects of the volute design parameters on the centrifugal compressor range of stable operation and pressure rise coefficient were investigated. In the theoretical study, effects of the symmetric and tangent volute area ratios on the diffuser pressure recopy factor and flow stability were investigated. In the experimental study, different configurations of a symmetrical and tangent (overhung) volutes with different are ratio, AR = 0.4 to 0.8 were investigated. Comparisons between the two different types of volute design parameters on compressor stable flow range and pressure rise coefficient were investigated. Effect of the clearance between the diffuser vanes and the volute casing on the compressor stability was investigated. This clearance was changed from zero to 0.4 of the impeller exit width in five tests. The pressure fluctuation leading to stall was observed at the vaneless region. Stall and surge were detected by analyzing both of the fluctuations of pressure signals and the power spectrum density. The effects of different volute configurations and clearance on stall initiation and hence compressor stable operation were discussed. The theoretical results show that increase in the symmetric volute exit radius increases the pressure recovery factor in the diffuser. The experimental data show that increase in the area ratio of symmetric and tangent volutes increases compressor range of stable operation as well as pressure rise coefficient.

KEYWORDS: *Volute, Stable operation, Flow coefficient, Stall, Surge*

NOMENCLATURE

AR	volute area ratio, A_3/A_2
b_2	impeller exit width, m
C	clearance, $C = c / b_2$
c	clearance between diffuser vanes and the volute casing, m
Ce	velocity in exit duct, m/s
Ci	velocity in inlet duct, m/s
Cp	pressure recovery in diffuser, $Cp = 2\Delta P_d / \rho U_2^2$
Pe	pressure at compressor exit, N/m^2
Pi	pressure at compressor inlet, N/m^2
P_r	pressure ratio
PSD	power spectrum density
ΔP	pressure rise, N/m^2, = Pe- Pi
ΔPd	pressure rise through diffuser, N/m^2
Q	volume flow rate, m^3/s
R	volute radius relative to the impeller exit width, $R = r / b_2$
r_2	impeller exit radius, m
r'_2	inlet volute radius, m
r'_3	exit volute radius, m
U_2	impeller tip speed, m/s
ρ	density, kg/m^3
Φ	flow coefficient = $Q/2\pi b_2 r_2 U_2$
Ψ	pressure coefficient $=2\Delta P / \rho\ U_2^2$

INTRODUCTION

The advantages of the aircraft turbocharger are to increase engine power output and to reduce noise and air pollutant products. The turbocharger compressor is required to develop an ever-increasing pressure ratio while maintaining a board operating range and good efficiency [1]. The current design trends in centrifugal compressors are to increase stage loading and to reduce the overall machine size [2-3]. Stability is a very important factor and one of the main concerns of compressor designers and users. As flow rate reduces, compressors have a limited stable operating range, due to occurrence of unsteady phenomena like rotating stall or surge. Rotating stall is a two-dimensional, local instability phenomenon in which one or more local regions of stagnant flow, so-called stall cells, rotate around the circumference of the compressor. While, surge is characterized by large amplitude fluctuations of the pressure and by unsteady, but circumferentially uniform, annulus-averaged mass flow. This essentially one-dimensional instability affects the compression system as a whole and results in a limit cycle oscillation in the compressor map. These instabilities can lead to severe damage of the machine due to large mechanical and thermal loads in the blading, and restrict its performance and efficiency.

However, different volute tongue geometries were studied using CFD analysis [4]. In this approach, the dynamics of the compression system are modified by feeding back perturbations into the flow field. Issac and et al. [5] experimentally investigated the effect of diffuser vane position and height on the low-speed compressor pressure coefficient. Several numerical and experimental studies have been performed for overhung volutes with an elliptical, rectangular or circular cross section [6]. Ayder [7] performed numerical and experimental studies based on an elliptical overhung volute using a multihole probe to measure flow parameters at several angular locations along the circumferential of the volute scroll. Japikse [8] studied the pressure recovery and the loss coefficients of three volutes with different area ratios.

Chapman, et al. [6] concluded that the volute has an important effect on the overall efficiency of the compressor. However, some investigations gave some proposals regarding the modifications of volute design aiming at better compressor pressure ratio and efficiency. Nevertheless, no previous trails were given on any details on the volute design to show and determine the effect of volute design on the compressor flow stability such as stall initiation, surge trigger and range of stable operation.

In present work, theoretical analysis were carried out for effect of different volute design parameters on the compressor stability and pressure rise. The compressor was tested experimentally with different volute configurations of a symmetrical or circular cross section area volute and with tangent inlet (overhung) volute. The area ratios of two different types of volutes were changed from AR=0.4 to 0.8 in five different tests. In addition, effect of the clearance between the diffuser vanes and the volute casing on the compressor stability was investigated. This clearance was changed from 0 to 0.4 of the impeller exit width in five tests. The fluctuations in wall static pressure were observed using pressure transducers with high frequency response in the vaneless region at different compressor operating conditions. The effects of volute design parameters on initiation of stall and surge were discussed by analyzing the pressure fluctuations and the corresponding power spectrum density using the Fast Fourier Transformation analysis.

2. Theoretical work

Since, the function of the centrifugal compressor volute or scroll casing is to collect and guide the flow from diffuser. Therefore, the target of the present theoretical study is to decrease the volute exit area aiming to eliminate or reduce the significant recirculation regions present within the volute discharge at the compressor low flow rates. This will leads to decrease the flow rate of unsteady operation of stall and surge and increase the pressure recovery through the volute thereby improving the overall efficiency of the turbocharger. Figure 1 shows a volute base circle radius (r'_2) is a little larger (0.07 times the diffuser radius) than the diffuser exit radius. Because, the vaneless space before volute decreases the non-uniformities and turbulence of flow entering the volute. Therefore, the volute exit to inlet area ratio has very important effects on the diffusion and loss into the volute flow processes [8] which can be written as:

$$AR = A_3 / A_2 = r'^2_3 / 2 r'_2 b_2 \qquad (1)$$

Where r'_2 and r'_3 is the inlet and exit radius of the symmetric or circular cross section area volute. The condition for a free vortex flow in the volute in which the angular momentum remains constant [9-10] is:

$$r' C_\theta = r'_2 C_{\theta 2} = r'_3 C_{\theta 3} = k \qquad (2)$$

Since, for a typical compressor-operating characteristic, the tangential velocity C_θ at any radius in the volute is approximately constant along constant speed line. Then the effective velocity through the volute that equals the velocity at section 3 is:

$$C_{eff} = C_3 = \dot{m} / r'_3 A_{eff} = Q / A_3 \qquad (3)$$

If the flow through the volute is assumed as incompressible and the inlet swirl parameter, $\lambda = C_{\theta 2} / C_{m2}$, where, C_{m2} is the radial velocity component. Then the velocity at sections 2, Fig. 1 is:

$$C_2 = (Q / A_2)(1 + \lambda^2)^{0.5} \qquad (4)$$

The pressure recovery factor through the diffuser is:

$$Cp = \frac{P_3 - P_2}{P_{02} - P_2} \qquad (5)$$

, and the loss coefficient is:

$$K = \frac{P_{02} - P_{03}}{p_{02} - p_2} \qquad (6)$$

Similar to Japikse [11] the meridional component of kinetic energy entering the volute is totally lost. Then, the component of the loss coefficient due to this effect is:

$$K_m = \frac{0.5 \rho C_{m2}^2}{0.5 \rho C_2^2} = \frac{1}{1 + \lambda^2} \qquad (7)$$

Nevertheless, for tangent volute, some of the meridional velocity effectively used in the downstream element and this will cause the fluid to rotate in the volute meridional plane.

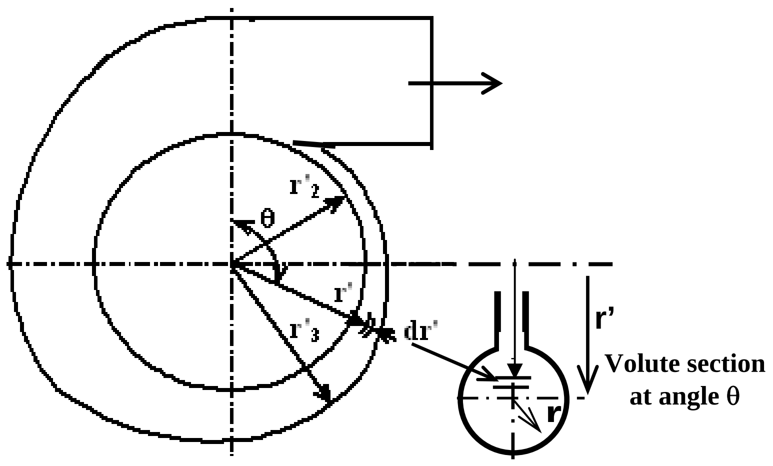

Fig.1: Centrifugal compressor volute

If the tangential flow accelerates in the volute ($C_{\theta 2} < C_3$ i.e. high flow rate) no losses occurs. Nevertheless, if the tangential flow decelerates ($C_{\theta 2} > C_3$ i.e. low flow rate) the flow diffuses.

In this case, the pressure loss is equivalent to the total pressure loss in a sudden expansion mixing process, which can be written as:

$$K_{\theta} = \frac{0.5\rho C_{\theta 2}^{2}(1-1/AR)^{2}}{0.5\rho C_{2}^{2}} = \frac{(\lambda - 1/AR)^{2}}{1+\lambda^{2}} \quad (8)$$

Combining Equs.7 and 8, gives two different loss relationship, depending on whether the flow condition is accelerated ($\lambda AR < 1$) or diffuses ($\lambda AR > 1$).

However, for accelerated flow ($\lambda AR < 1$), the pressure recovery factor (Equ. 7) using these losses can be written as:

$$Cp = \frac{(\lambda^{2} - 1/AR^{2})}{(1+\lambda^{2})} \quad (9)$$

While, for diffuses flow ($\lambda AR > 1$), it can be written as:

$$Cp = \frac{2(\lambda - 1/AR)}{AR(1+\lambda^{2})} \quad (10)$$

The pressure recovery factor and the loss coefficient with the symmetric volute in case of diffuses flow are shown in Figs. 2 and 3 respectively. Figure 2 shows that increasing the volute area ratio increases the pressure recovery factor in the diffuser. The theoretical analysis results were compared with one the experimental results for volute specifications at area ratio AR = 0.8. It is clear in this figure that the experimental results show very good agreements with the theoretical data expect at the peak of the pressure recovery factor in the experimental give higher-pressure recovery factor than the theoretical results. This is because there are different losses were considered in the theoretical models beside the compressibility effects. Figure 3 shows that from the theoretical results of the symmetric volute at different area ratio the volute loss coefficient increases with increase in the exit swirl parameter of the diffuser. The volute loss coefficient increases with increase in the volute area ratio due to increase the eddy and friction in the volute with large area.

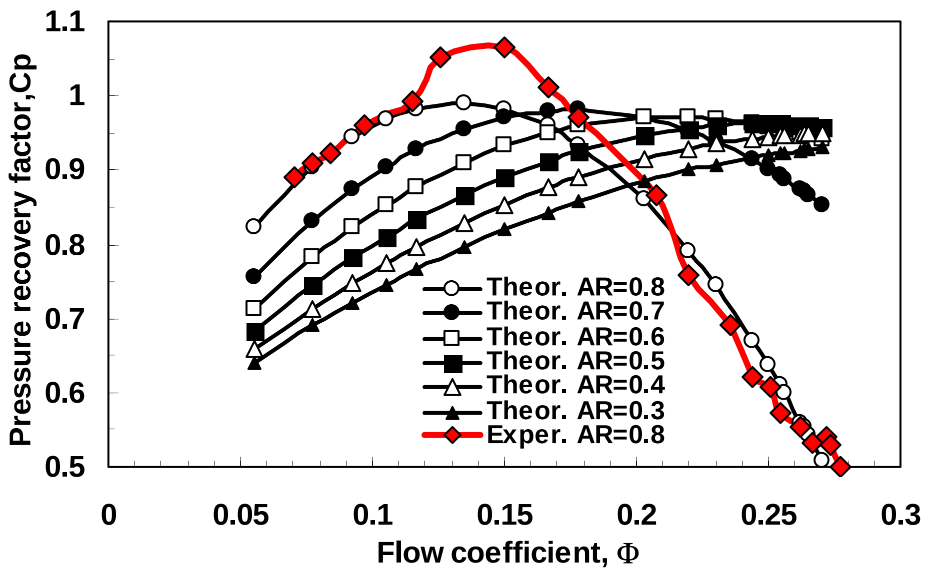

Fig.2: Pressure recovery factor in the diffuser, from the theoretical work at different volute area ratio and the experimental with the same specifications of symmetric volute

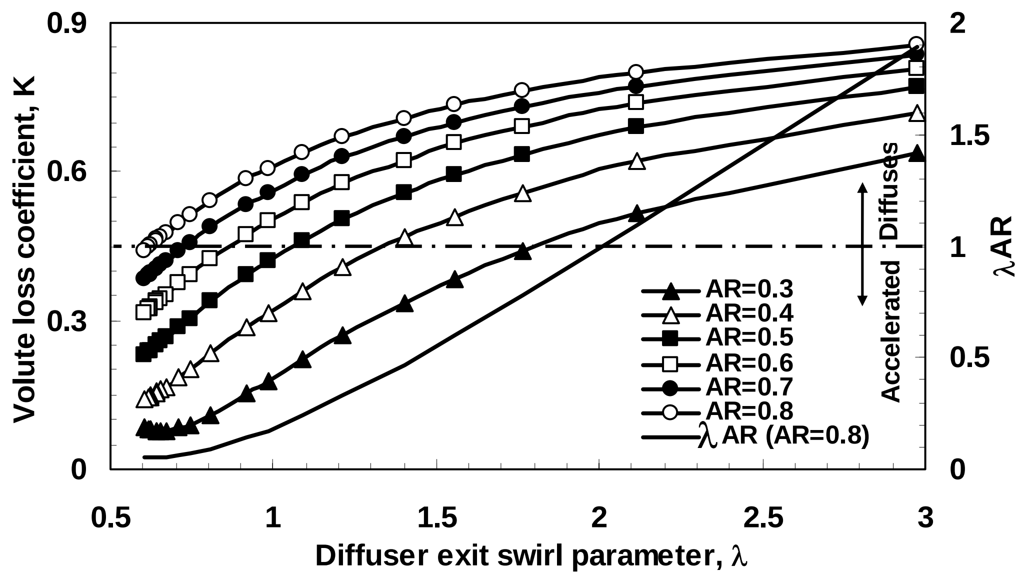

Fig.3: Loss coefficient at different area ratio of the symmetric volute

This noticeable increase in the volute loss coefficient with increase in the volute area ratio at especially higher diffuser exit swirl can be attributed to increase of non-uniformity pressure. The loss relationship λAR depending on whether the flow condition corresponds λAR<1 (for accelerated flow through the volute) or λAR>1 1 (for diffuses flow through the volute).

On the other hand, the volume flow rate through an infinitesimal section of cross section ($b_\theta dr'$) at an angular position, θ, Fig. 1 using Equ.2 is:

$$Q_\theta = \int_{r'_2}^{r'_3} k b_\theta dr'/r' \tag{11}$$

The present analysis assumed constant mean velocity and pressure along the volute passage. However, for a given value of the mean velocity C_m the volume flow rate is:

$$Q_\theta = C_m A_\theta = \theta Q/360 \tag{12}$$

From Equs. 11, 12 and using the definition of volute width at θ position, then:

$$Q_\theta/360 = k\int_{r'_2}^{r'_3} 2\sqrt{r'^2_\theta-(r'-r'_2-r'_\theta)^2}\, dr'/r' = 2\pi k r'_2\,(1+R_\theta-\sqrt{1+2R_\theta}) \tag{13}$$

Where, R_θ is the volute outlet radius relative to the volute radius at the tongue at the angular position θ. However, the ratio θ/θ_t is:

$$\theta/\theta_t = (1+R_\theta-\sqrt{1+2R_\theta})/(1+R_{\theta t}-\sqrt{1+2R_{\theta t}}) \tag{14}$$

Where θ_t is the angle at the volute tongue, then from Equ.13 the free vortex, k, is:

$$k = \frac{Q\theta}{720\pi r'_2\,(1+R_\theta-\sqrt{1+2R_\theta})} \tag{15}$$

Substituting Equ.15 into Equ.14, R_θ ($R_\theta = r'_{Ve}/r'_t$) at angular position θ is:

$$R_\theta = (\theta/\theta_t)(1+R_{\theta t}-\sqrt{1+2R_{\theta t}}) \pm \sqrt{2(\theta/\theta_t)(1+R_{\theta t}-\sqrt{1+2R_{\theta t}})} \tag{16}$$

Where, r'_{Ve} is the volute exit radius at angular position θ ($r'_{Ve} = r'_3$) and r'_t is the volute radius at the tongue of an angular position θ_t. However, Equ.16 can be written as a function of the volute area ratio AR as follows:

$$R_\theta = (\theta/\theta_t)(1 + AR(2b_2/r'_{Vt}) - \sqrt{1+2AR(2b_2/r'_{Vt})})$$
$$\pm\sqrt{2(\theta/\theta_t)(1 + AR(2b_2/r'_{Vt}) - \sqrt{1+2R_{\theta t}}AR(2b_2/r'_{Vt}))} \qquad (17)$$

The volute exit radius relative to the radius at the tongue as a function of the volute area ratio AR, at different angular position, θ, are shown in Fig. 4. It is clear in the figure that the present actual compressor volute of the aircraft turbocharger has radius ratio, R_θ, little bit higher at different volute angular position in comparison with the theoretical results at the same area ratio, AR =0.8. This can be attributing to the assumption that considered in the present theoretical work which assumed maintain constant velocity of the fluid in the volute passage and uniform static pressure distribution around the impeller. Nevertheless, in the actual practice, the velocity and pressure vary across the cross section of the volute passage at a given section. However, it can be concluded that the theoretical results are in acceptable agreements with the actual data.

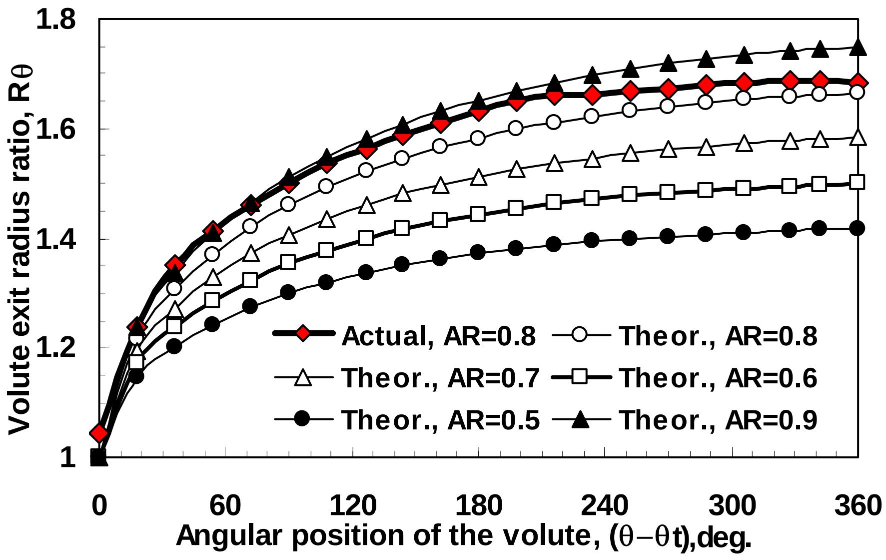

Fig.4: Predicted and actual volute exit radius ratios, R_θ as a function of the volute area ratio, AR angular at different angular position, θ.

3. EXPERIMENTAL WORK

3.1 The Experiment Test Facility

The test rig used for this work consisted of an open loop centrifugal compressor driven by a variable speed motor with a power input of 5 kW. The compressor is released from an actual aircraft turbocharger (Allis Chalmers type, AN D 132, licensed under general electric company of serial No. 57153 CH model 7S-B22-A6, made in USA). A frequency controller accurately controlled the speed of the motor. The test compressor is constructed from radial blade impeller, parabolic vanes diffuser and volute casing. Fig.4 shows a photographic picture of the experimental test facility. The compressor draws air at atmospheric conditions and discharges into a large tank followed, by an orifice flow meter and control valve for measuring and controlling the flow rate. Wall pressure taps are installed along the front casing of the whole compressor passage to detect the pressure rise between these taps and the inlet to the compressor. These taps are located in front of the impeller passage in the vaneless space between the impeller exit and diffuser vanes inlet and at diffuser exit.

Three high sensitivity semiconductor-type pressure transducers of omega type, PX-236-100GV silicon diaphragm with full bridge are incorporated to the compressor casing. Two transducers are jointed into the vaneless region with 90-degrees shift through the circumference at same radius. A DC amplifier (SENSOTEC'S SA-BII) receives the output signals from the pressure transducers and provides a 16-bit A/D converter board (multi-function acquisition card) supported into PC-SCOPE software for simultaneously pressures for one second at a rate of one kHz. The board is supported by PC-SCOPE software, which turns the computer to oscilloscope and stores the pressure waveforms in ASCII file. Subsequently the data in the file were processed using the Fast Fourier Transformation Analysis (FFT) to estimate the Power Spectrum Density (PSD) by Welch's averaged, modified periodogram method for discrete-time signal vector.

Fig.4: Photographic picture of the experimental test facility.

3.2 Uncertainty Analysis

The compressor rotor speeds were measured using tachometer with maximum uncertainty of ±10 rpm that covers full scale of 3500 to 4500 rpm. Individual temperature measurements were made with mercury thermometers with uncertainty of ± 0.5 ^{o}C. The air mass flow rates were measured in kg/s,($\dot{m}$), was made using a calibrated orifice meter of correlated equation

$$\dot{m} = 0.000443\{1-[0.331(p_{up}-p_{down})/p_{up}]\}\{[p_{up}(p_{up}-p_{down})]/T_1\}^{0.5}$$

where p_{up} and p_{down} are upstream and downstream pressures at the orifice meter in Pa with maximum uncertainty of ±10 Pa and T_1 is the air temperature at orifice meter in Kelvin. The pressure transducers combined with the amplifier and PC, used for measuring the rest of static pressures, were calibrated using a dead weight gage with maximum uncertainty of ±15 Pa.

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1. Characteristic of the compressor with tangent inlet volute

The compressor characteristic curve with the symmetric volute of an area ratio of AR = 0.8, and clearance ratio, C = 0.1 is shown in Fig. 5. The ordinates are the pressure coefficient, Ψ, the pressure recovery factor in the diffuser, Cp and the abscissa is the flow coefficient, Φ. The time variation of wall static were measured at about 20 different operating points from compressor maximum flow rate to very low flow rate. The detections of stall initiation and surge are based on examining all the static pressure time variation and PSD graphs at the vaneless region of the measured data under different flow rates. Four flow conditions (denoted: A, B,C and D) to describe the flow during its progressing from steady flow to the stall initiation and to surge trigger as an example for how the compressor flow instabilities were detected in the experiments. Where point (A) is the maximum flow rate, B is the maximum Ψ and Cp, C is the in stall condition and D is in critical condition of surge as discussed later.

The fluctuations of pressure static rise and the corresponding power spectrum density for the compressor of symmetric volute, AR=0.8 and C = 0.1, at four different operating conditions are shown in Fig 6. At compressor operating point A, Φ = 0.271, Fig.6a, shows the compressor runs stably where both the amplitude of pressure fluctuations and the corresponding PSD at the diffuser inlet are very small. At the operating point B of maximum pressure rise, Φ = 0.151, Fig.6b, the compressor shows a little bit increase in both the amplitudes of pressure fluctuations and PSD where the compressor is still operating in the range of stable operation. When the compressor operating at the flow coefficient Φ = 0.115 (point-C), as shown in Fig.6c, the amplitude of pressure fluctuations reaches about 20% of compressor maximum pressure coefficient with frequency of 17 Hz, where the compressor is expected to run in present of rotating stall. As the compressor operates at lower flow rate, Φ= 0.097, the amplitude of pressure fluctuations reaches about 35% of compressor maximum pressure coefficient with predominant surge frequency of 8 Hz [12], as shown in Fig.6d.

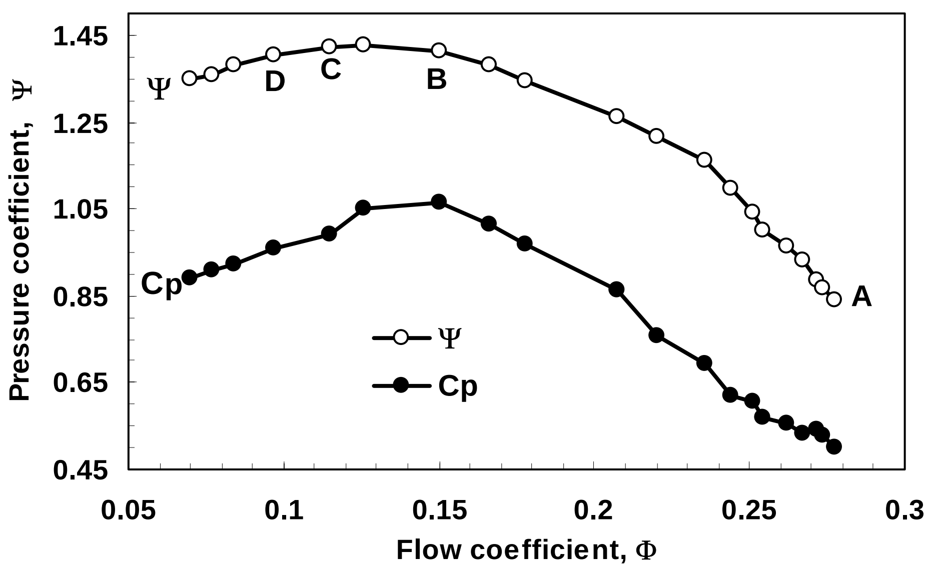

Fig.5: Compressor with symmetric inlet volute, AR= 0.8 and C = 0.1

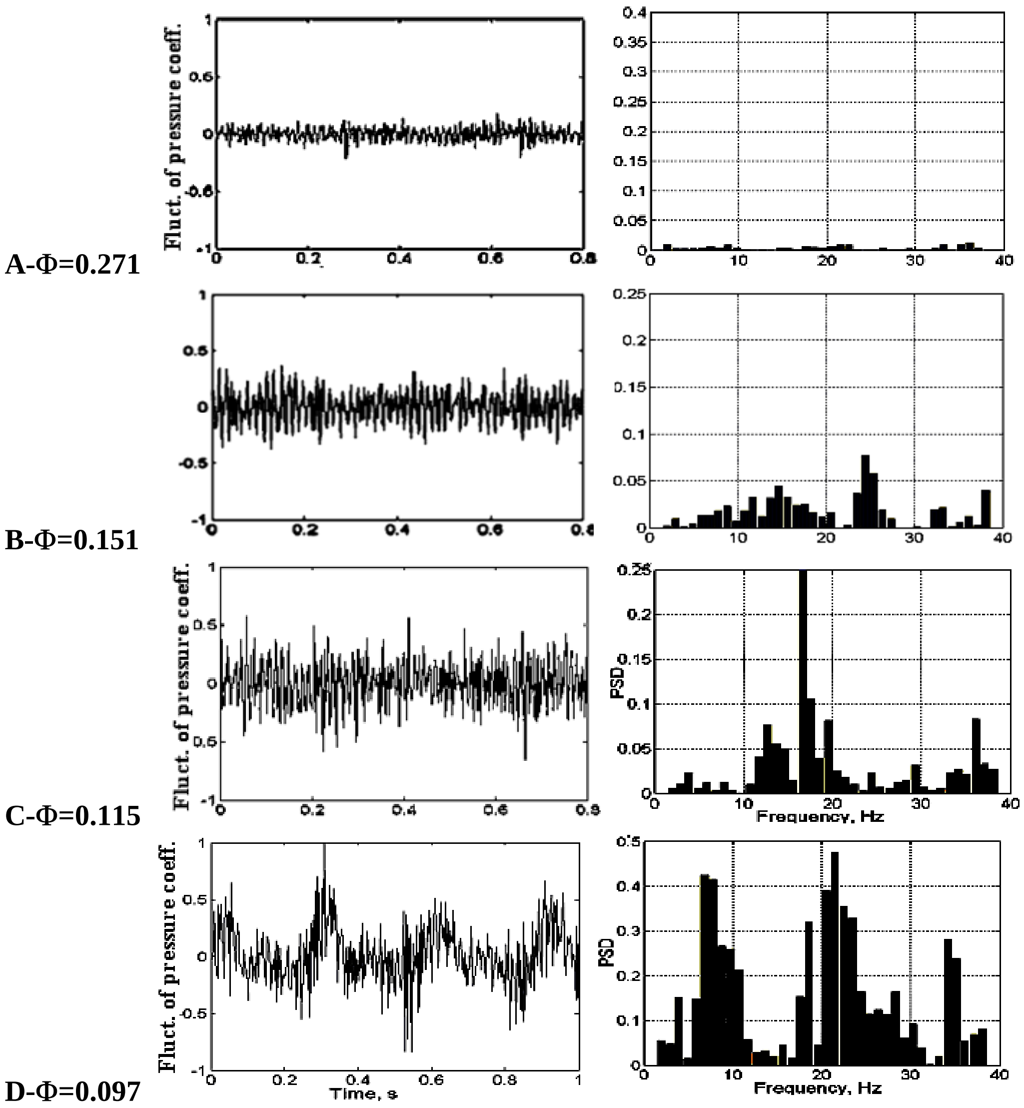

Fig.6: Fluctuations of static pressure rise and corresponding power spectrum density for the compressor of symmetric volute, AR = 0.8 and C = 0.1

4.2. Effect of different volute design parameters on the compressor pressure rise and range of stable operation

Several numerical and experimental studies have been performed for overhung volutes with an elliptical, rectangular or circular cross section as mentioned in the introduction. The above-mentioned investigations gave some proposals regarding the modifications of volute design aiming at better compressor pressure ratio and efficiency. No previous trails were given on the effects of volute design on initiation of stall, surge and range of stable operation. The present paper focused on effect of reducing the volute exit area and effect that on the unsteady phenomena due to stall initiation and surge beside the classical compressor characteristic of pressure rise confident, pressure recovery factor and maximum flow rates.

4.2.1 Symmetric volute

Figure 7 shows effects of area ratio, AR, of the symmetric volute or circular cross section area on the compressor pressure coefficient Ψ and flow coefficient Φ. This figure shows increasing of compressor pressure rise coefficient as well as compressor maximum flow rates with increasing the volute area ratio, AR. This can be attributed to the increasing the velocity gains from the diffuser with decreasing the boundary layer loss. At the compressor low flow rate in positive slope of the compressor characteristic curve, the volutes of area ratios, AR = 0.6 and 0.7 give higher-pressure rise coefficients than the larger volute of AR =0.8. This means that there is an optimum symmetric volute radius at low flow rate operation. That is at large volute area ratio, AR, and operation the compressor at low flow rates reverse flow may be occurs due to flow separation or recirculation regions present within the volute. On the other hand, when the compressor was tested with a volute had low value of area ratio, low of pressure coefficient as well as range flow rate was observed.

Figure 8 shows the effect of symmetrical volute area ratio AR on the compressor flow stability or critical flow coefficient for stall initiation. The points of stall initiation at different symmetrical volute AR ratio and at different compressor tests speed are shown in the figure.

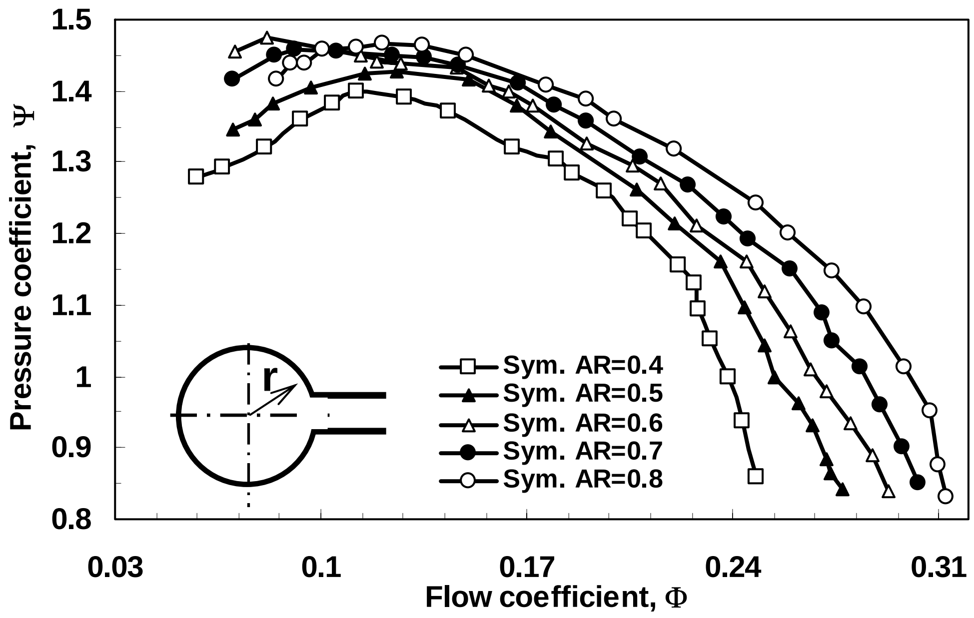

Fig. 7: Effect of symmetric volute area ratio on the compressor performance

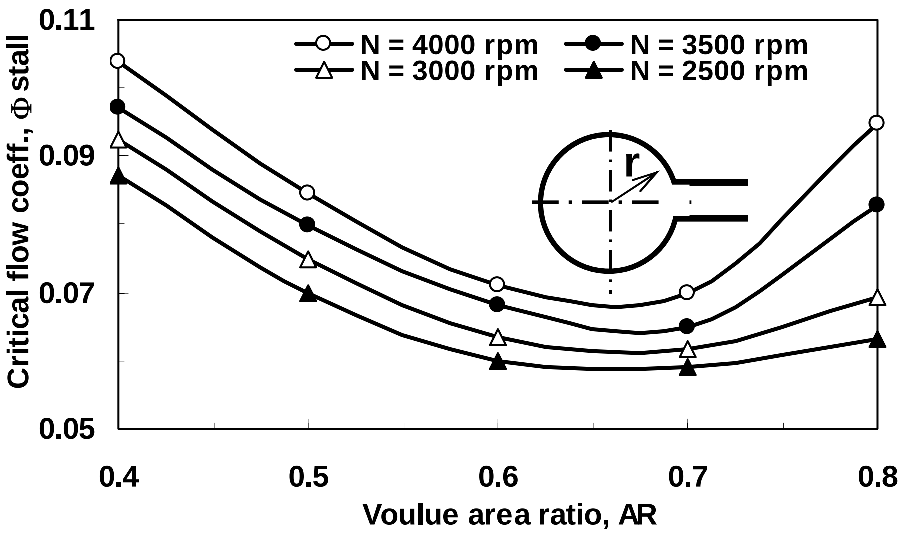

Fig. 8: Effect of symmetric volute area ratio on the critical flow rate

It is clear in Fig. 8 that the ranges of symmetrical volute are ratio AR between 0.6 - 0.7 gives the lower flow rate for stall initiation. This means that the compressor with these volutes runs stably until low flow rates than the compressor with the other volutes. That is at the range of volute area ratio, AR of 0.6 to 0.7 the separation inside these volutes occurs at low flow rates than the other volutes. Of course, the rotating stalls were initiated at higher flow rates with high-speed operation than that a low speeds due to higher kinetic energy entering the diffuser and higher-pressure recovery factor in the diffuser at the higher speeds.

On the other hand, the ranges of stable operation of the compressor with the symmetrical volute of different area ratios AR at different compressor speed are illustrated in Fig.9. This figure shows increasing the range of stable operation of the compressor with increasing the rotor speeds. The symmetrical volute area ratio, AR, ranging from 0.6 to 0.7 gives the maximum range of stable operation (maximum to minimum flow rate of stable operation). This result is confirmed that there is an optimum volute cross section area of specified area ratio ranges from AR= 0.6 to0.7 to give the maximum range of stable operation and pressure coefficient.

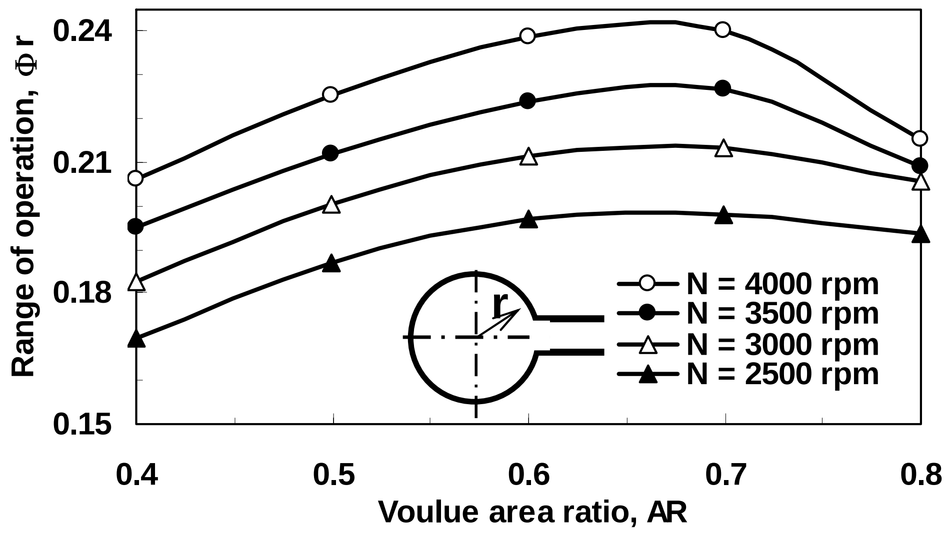

Fig. 9: Effect of symmetric volute area ratio on compressor range of stable operation

4.2.2 Overhung or tangent inlet volute

The compressor was tested with tangent inlet or overhung volute at different cross section area ratio of , AR, ranging from AR = 0.4 to 0.8, in five separate tests and the results were compared with symmetric volute as shown in Fig. 10. This figure clearly shows that the area of the tangent volute has a pronounced effect on the compressor maximum flow rate as well as compressor pressure coefficient. Increasing tangent volute area ratio gives increases the compressor maximum flow rates and pressure rise coefficient. In addition, the compressor with tangent volute gives higher-pressure coefficient and maximum flow rate than the compressor with the symmetric volute as the same volute radius ratio (AR). This is due to increase in diffuser pressure recovery with the tangent volute than with the symmetric volute. Figure 11 shows comparisons between the two different types of the volutes of symmetric and tangent inlets at different volute area ratio of the two types. This figure clearly shows the compressor with the tangent volute gives higher maximum pressure coefficients than with the symmetric volute at different volutes area ratio. The compressor with the tangent volute gives also large in stable operation than the compressor the symmetric volute.

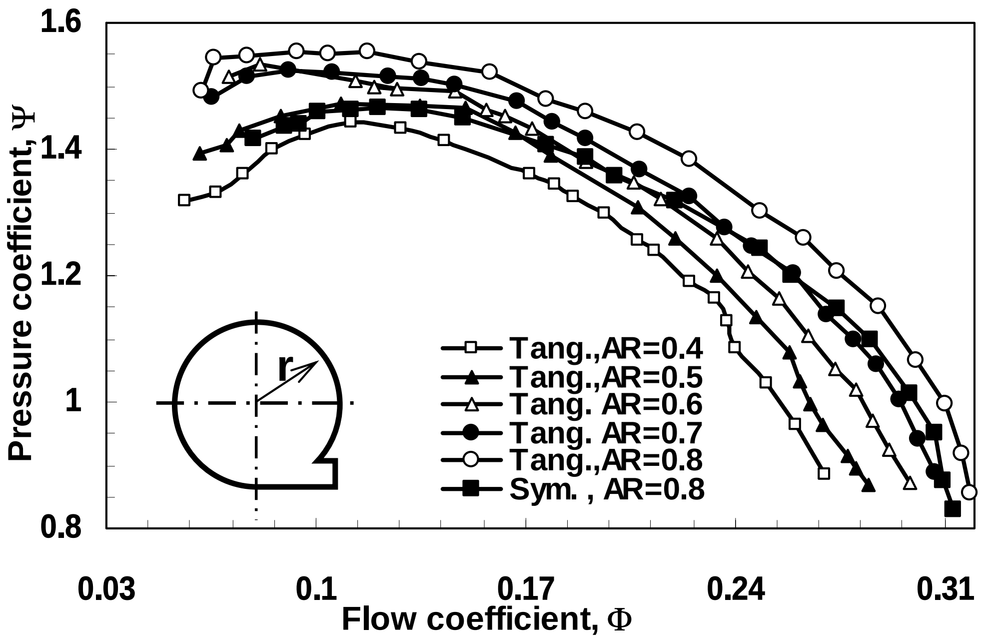

Fig. 10: Effect of area ratio of tangent volute and comparison with symmetric volute

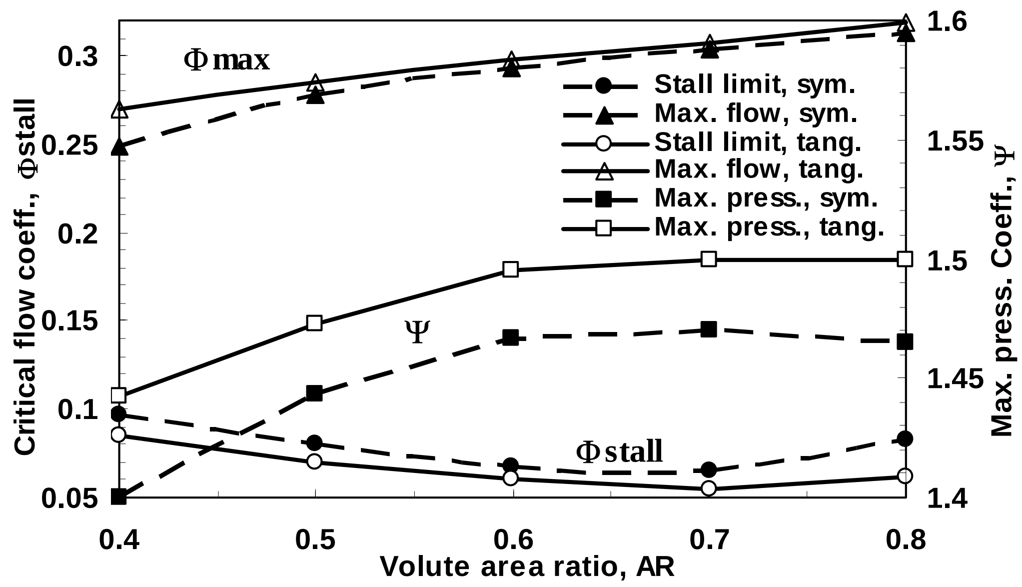

Fig. 11: Comparison between the tangent and symmetric volutes

4.3. Influence of the Clearance between the diffuser vanes and the volute casing on the compressor pressure coefficient and the range of stable flow operation

Figure 12 shows the influence of clearance ratio, ($C= c/b_2$) between the diffuser vanes and the volute casing on the compressor pressure coefficient. This figure clearly shows that when the clearance ratio, C, is increased the compressor maximum flow coefficient is increased. Nevertheless, decreases the clearance ratio, C, increases the peak pressure coefficient. In addition, this figure shows influences of the compressor stable flow range by changing the clearance between the diffuser vanes and the volute casing from zero to 0.4. Increasing the clearance between the diffuser vanes and the volute casing gives a decrease in flow coefficient at unsteady operation of low flow rates. This is may be due to decrease of the flow separation at the diffuser flow passages with increasing the clearance between the diffuser vanes and the volute casing. However, more accurate results were obtained at different clearance between the diffuser vanes and the volute casing from using the high frequency response pressure transducers. Figure 13 shows the critical flow coefficient at stall initiation that indicates the limit of stable operation at low flow rate. It is clear from the figure that the flow coefficient at stall initiation decreases by increasing the clearance ratio, ($C = c/b_2$) between the diffuser vanes and the volute casing.

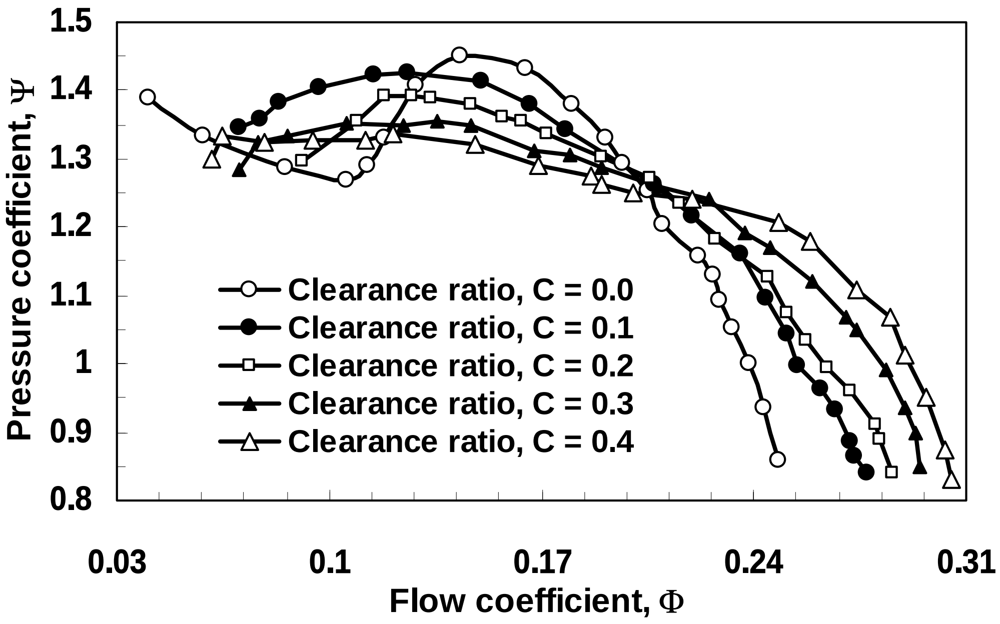

Fig. 12: Effect of clearance on the compressor pressure coefficient

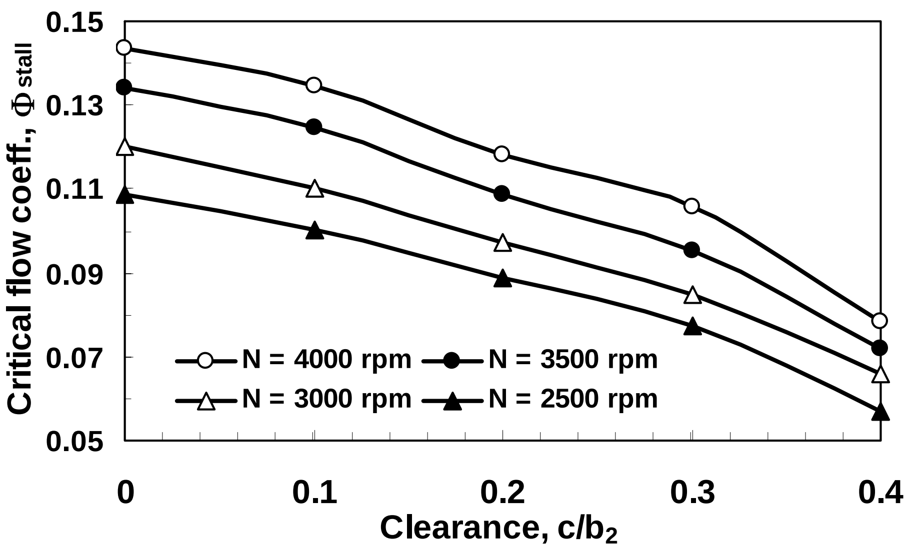

Fig. 13: Effect of clearance between the diffuser vanes and the volute casing on the stall initiation at different tested speeds

Figure 14 shows effect of clearance between the diffuser vanes and the volute casing on the compressor pressure coefficient and range of stable flow operation at different tested speeds of 4000 rpm, 3500 rpm, 3000 rpm and 2500 rpm. This figure clearly shows increase in compressor range of stable operation with increase in clearance between the diffuser vanes and the volute casing at different speeds. However, the compressor pressure coefficient increases by decreasing this clearance. That is the development of sidewall boundary layer mainly depends upon the pressure rise coefficient. As the pressure coefficient increases with decrease the clearance ration, the sidewall stalls at a larger flow rate and the flow range of stable operation is narrower.

On the other hand, as the clearance ratio increases the pressure coefficient decreases at the compressor low flow rates but the range of stable of operation is wider. Because, with the large clearance between the diffuser vanes and casing the sidewall boundary layer separates from the wall due to the steep radial pressure gradient. Therefore, it is very likely that the cause of stall is the separation of the sidewall boundary layer. It is concluded that the separation of boundary layer along the sidewall is the main cause of rotating stall. However, in case of small clearance between the diffuser vanes and the volute casing the compressor pressure coefficient increases because the pressure recovery coefficient is increased as the flow rate is reduced and the diffuser stabilizes the characteristic curve of the compressor. Nevertheless, in the case of large clearance between the diffuser vanes and the volute casing, it is not likely that the pressure recovery coefficient various discontinuously at a certain inlet flow condition. However, that even if a separation or rotating stall occurs the pressure losses is increased.

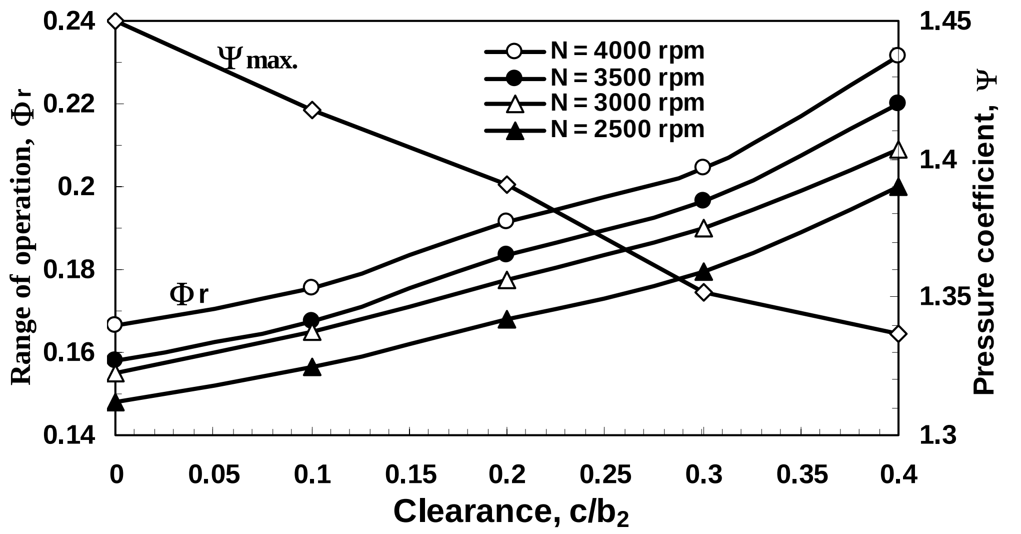

Fig. 14: Effect of clearance on range of stable operation at different tested rotor speeds

5. CONCLUSIONS

Influence of the volute design parameters on the a centrifugal compressor of aircraft turbocharger range of stable operation and pressure rise coefficient as well as diffuser pressure recovery factor has been investigated theoretically and experimentally. In the theoretical work, effects volute area ratios and diameter on the diffuser pressure recopy factor and compressor flow stability were investigated. In the experimental work, symmetrical and tangent volutes with different area ratio were investigated. Comparisons between the results of the two different types of volute design parameters on compressor stable flow range and pressure coefficient were investigated. Effect of the different clearances ratio (zero to 0.4) between the diffuser vanes and the volute casing, relative to the impeller exit width on the compressor stability was investigated. Stall and surge were detected by analyzing both of the fluctuations of pressure

signals and the power spectrum density in the different tests. Comparisons between the theoretical and experimental results were done and show acceptable agreements.
The theoretical results show that:

- The diffuser pressure recovery factor increases as the volute area ratio increases.
- The volute loss coefficient increases with increase the symmetric volute area ratio.
- The present actual compressor volute has a little bit higher radius at different volute angular position relative to the obtained theoretical result.

The experimental results show that:

- Increasing volute area ratio gives increase in the compressor maximum flow rates and pressure rise coefficient.
- There is an optimum area ratio of volute ranging from AR = 0.6 - 0.7 that gives maximum range of stable operation.
- The compressor with tangent volute gives larger range of stable operation, higher-pressure coefficient and maximum flow rate than the compressor with the symmetric volute at the same volutes area ratio.
- The range of compressor stable operation increases with increase the clearance between the diffuser vanes and the volute casing at different speeds.
- Decrease the area ratio from 0.8 to 0.7 increases the range of stable operation due to eliminate or reduce significant recirculation regions within the volute discharge which leads to increasing pressure recovery and hence improving the overall turbocharger efficiency.

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