AERODYNAMIC CHARACTERSTICS OF CURVATURE BLADE CASCADE

Part 1. Static Case

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ABSTRACT:

An experimental investigation of aerodynamic properties of the fixed curvature blade cascade has been carried out. This experimental study is concerned with the determination of the blade losses, which are due to the pressure drop of air flow along the blade height. These losses are divided into; total; profile; and secondary losses. The fixed blade profile of steam turbine, $N(90^{o}-15^{o})$, was chosen and an experimental set was designed and constructed to carry out this investigation; for the flow Mach number ranges from 0.2 to 0.8. The aerodynamic losses, at several stations along the blade high, were found to be affected by the change of flow Mach number. Their values were decreased with an increase in the value of flow Mach number, from 0.2 to 0.6 and then started to rise for flow Mach numbers greater than 0.6. So the smallest values of blade losses or the best values of cascade efficiency were obtained when the flow Mach number is equal to 0.6.

1. INTRODUCTION:

The aerodynamic characterestics of turbomachine blade rows have considerable importance because the performance of turbomachine blade rows are very much affected by the characteristics of blades and their relation to the overall blade losses. So the turbine blade losses are very important and play a vital role in the design of turbomachines. A literature survey clearly indicates that, the number of published papers, dealing with the effect of Mach number on the blade losses along the blade height in the curvature blade cascade are limited. However, Most of them are concerned with the determination of blade losses in a straight cascade, [1 - 5]. Mobark, et al. [1], studied the influence of blade aspect ratio, changed from 0.145 to 0.664 and for the cascade exit flow Mach number ranged from 0.4 to 0.6, on the total energy loss coefficient and on the straight cascade efficiency. Their results showed that, the cascade total energy loss coefficient decreases with an increase of the blade aspect ratio. Sabry and Ibrahim [2], studied the effect of Mach number has values ($0.2 < M < 0.5$) and blade profile on the characteristics of blades, for different values of relative pitch, using a straight air flow blade cascade. Their results showed that, the blade profile and the Mach number used have a significant effect on the blade losses. Herzing and Hansen [3], studied the secondary flow phenomenon in turbomachines for Mach numbers blow 0.4.

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They found that, the upstream wall boundary layer was swept across the blade passage. Sieverding and Wilputte [4], studied experimentally the effect of Mach number and end wall cooling on the secondary flow in a straight nozzle cascade. The tests were performed for the outlet Mach number, 0.1, 0.6 and 0.8. Their results showed that, the secondary losses started to increase for both cases of low speed and high speed flows. Gogoler, et al. [5], studied the effect of blade chord on the friction losses in a straight blade cascade of relative pitch depends on the existence of flow separation. The decrease in the blade chord causes a monotonic increase in the friction losses.

The primary aim of the experimental investigation described here was to determine the effect of Mach number and the distance along the blade height on the energy losses through the curvature blade cascade for the wide range of Mach number ($0.2 < M < 0.8$). Total pressure difference measurements across the blade cascade pitch; at several stations along the blade height; were obtained for some flow conditions using a standerd blade nozzle profile, N(90^o-15^o).

NOMENCLATURE:

b	:	Blade chord
D	:	Curvature cascade diameter
ΔE_d	:	Blade edge thickness
L	:	Blade hight.
P_1	:	Static pressure at cascade inlet.
P_2	:	Static pressure at cascade outlet.
P_{o1}	:	Stagnation pressure at cascade intle.
P_{o2}	:	Stagnation pressure at cascade outlet.
S	:	Distance along the blade heigh.
ΔP_i	:	Total pressure difference, $P_{o1}-P_{o2}$ Equ. (1).
ΔP_o	:	Pressure difference, $P_{o1}-P_2$, Equ. (1).
t	:	Blade pitch
x	:	Distance along the blade pitch.
α_o	:	Inlet flow angle.
α_1	:	Outlet flow angle.
α_y	:	Angle of blade setting.

DIMENSIONLESS GROUPS:

K	:	Specific heat ratio
$\grave{L}$	:	Blade height/chord ratio = L/b
M	:	Mach number
$\grave{t}$	:	Relative pitch = t/b.
ε	:	Pressure ratio = P_2/P_{o1}
ζ_{pr}	:	Profile loss coefficient
ζ_s	:	Secondary loss coefficient
ζ_t	:	Total loss coefficient.

2. APPARATUS AND MEASURING TECHNIQUES:

The experimental set, shown in Fig. (1), consists of; the cascade arrangement; supply line and control systems; and the measuring instruments. Two angles of wood were used as an air guide at the entrance of cascade to obtain an uniform flow upstream of blade channels and the angles were placed in such away that to allow an air inlet angle of 90^{o}. The air flows in an open circuit shown in Fig.(1). Air compressors (1) were used to give the required discharge and pressure. The air flows from the compressors through a pipeline to the air tank and dryer unit; includes oil and water separators (2), after this unit the air flows to the air tunnel (4) and then to the test section which contains the row or curvature cascade of blades set in a mounting device such that various cascade air inlet and outlet angles can be obtained. The air flow rate and the pressure at the entrance to the air tunnel is controlled by air tank and the pressure reducing valve (3).

2.1- Measuring Instruments:

The measurements were taken at different values of Mach number. The following table shows the specifications for the standard fixed blade profile, N(90^{o}-15^{o}) used here.

b mm	$\grave{L}$=L/b	$\grave{t}$ = t/b	ΔE_d mm	α_o degree	α_1 degree	α_y degree
33.33	1	0.75	1	90	15	38

For determing the aerodynamic characteristics of air flow blade cascade, pressure measuring devices are used. In this experimental work, the stagnation pressure before and after the cascade blade, in the air tunnel and the outlet flow angle were measured. The outlet flow angle was kept constant, during the experiments, at 15^{o}. The difference between the stagnation pressure in air tunnel and the atmospheric pressure was measured for the determination of the required Mach number by using the gas-dynamic table.

3. RESULTS AND DISCUSSION:

3.1- Total Pressure Distribution:

A representative selection of total pressure drop measurements (ΔP_i) across the blade pitch are shown in Figs. (2-4). These values of (ΔP_i)[1] were measured at several stations along the blade cascade height, S, for different values of flow Mach number, M. Curves of (S=0) represent the results which are taken at the center of the blade cascade height, while other curves are for (S$>$0) represent the results at variable distances (S) along the blade height (The distance S was measured from the mid height of the blade to the top of blade height). From each figure, it can be seen that the maximum total pressure drop (difference between the stagnation pressure, before and after the fixed curvature blade cascade) occurs at the trailling edge of the blade. While the minimum total pressure drop occurs some where in the pitch depending upon the Mach number and the distance, S. This can be explained as the velocity distribution is not symmetrical with respect to the trailing edge due to its finite thickness and hence blade wake will be formed; i.e. the velocity of air in the blade wake must be smaller than that of the main flow and a part of kinetic energy is exhausted in generation and maintenance of vortices.

This will lead to a higher total pressure difference at the trailing edge than that in the main flow. These values of total pressure difference are varies from figure to the another according to the values of flow Mach number, M, and the distance, S.

3.2- Profile Loss Coefficient:

The profile loss coefficient is obtained from the following equation, ref. [2] :

$$\zeta_{pr} = \varepsilon^{\frac{k-1}{k}} \cdot \frac{1-\left[1-\frac{\Delta P_i}{\Delta P_o}(1-\varepsilon)\right]^{\frac{k-1}{k}}}{\left[1-\varepsilon^{\frac{k-1}{k}}\right]\left[1-\frac{\Delta P_i}{\Delta P_o}(1-\varepsilon)\right]^{\frac{k-1}{k}}} \quad \ldots\ldots (1)$$

This equation was used by previous investigators for determing the profile loss coefficient in air flow straight blade cascade. Alexeeva and Boussova [6], found that Equ. (1) may also be used for obtaining the profile loss coefficient in curvature blade cascade of higher values of curvature diameter to the blade height ratio ($\frac{D}{L} > 3$). Since in our experimental work (D/L) is about 12. Therefore, the assumption of using Equ. (1) here is valied. In Equ. (1), ($\Delta p_i/\Delta p_o$) is the average value along the pitch. This average value calculated from different measurements along the pitch at the center of the blade cascade cascade (S=0) and also at variable distances (S) along the blade height, for different values of Mach number. The corresponding results are illustrated in Figs. (5 and 6). From these figures, it can be seen that, for each value of (S), the profile loss coefficient decreases with the increase of Mach number ($0.2 < M < 0.6$), while for higher values of M($0.6 < M < 0.8$), (ζ_{pr}) increases slightly with the increase of (M). This can be explained as an increase of (M), ($0.2 < M < 0.6$), the flow density decreases, which causes a decrease in the boundary layer thickness, on the other hand an increase in the value of M causes an increase in viscosity, both effect together lead to a decrease in the (ζ_{pr}) as (M) increases. For ($M > 0.6$), the diffusion flow becomes more intensive, and then (ζ_{pr}) increases. The results in Figs. (5 and 6) also indicate that, for each value of (M), the (ζ_{pr}) decreases with the decrease of the distance (S).

3.3- Total Loss and Secondary Loss Coefficients:

Fig. (7) shows the variation of the total loss (ζ_t), the profile loss (ζ_{pr}) and the secondary loss (ζ_s) coefficients with the flow Mach number, M. In this figure the profile loss coefficient was measured at (s=0), the total loss coefficient was determined from Fig. (5), by counting the area under each curve, where (M) has a constant value. The value of (ζ_s) was calculated, for each value of M, from the following relation.

$$\zeta_s = \zeta_t - \zeta_{pr\ (s=o)}$$

From Fig. (7), it can be seen that, (ζ_t) decreases with the increase of M, ($0.2 < M < 0.6$), while at $M > 0.6$ the value of (ζ_t) starts to rise slightly. This can be explained as was discussed previously for the (ζ_{pr}). The same trend for the secondary loss coefficient was observed. These

These secondary losses in a turbomachine blade passage are caused due to the combined effect of the blade curvature and the boundary layers on the annulus walls. Fig.(7) also indicates that, for the blade profile used $N(90^{\circ}-15^{\circ})$, the minimum value of losses occurs at $M = 0.6$, i.e. the best value of cascade efficiency occurs at $M=0.6$.

4. CONCLUSIONS:

The aerodunamic characterstic of fixed blades of steam turbines has been studied by means of fixed curvature blade cascade, $N(90^{\circ}-15^{\circ})$, for the range of Mach number $(0.2 < M < 0.8)$. The major conclusions and results of this study are summarized below :

1- The total pressure difference, across the curvature blade cascade was measured at variable distances along the blade height and for different values of flow Mach number. It has a maximum value at the trailing - edge, while at the midle of pitch has nearly a constant value for a certain value of (M) and (S). The total pressure difference was found to be affected by both of (M) and (S).

2- The profile loss coefficient was found to decrease with the increase of Mach number until $(M=0.6)$, after that value of M, the profile loss coefficient increases with the increase of (M). The distances along the blade height were found to have asignificant effect on the profile loss coefficient.

3- The total and secondary loss coefficients were found to decrease with the increase of flow Mach number until $(M=0.6)$, after that value they started to increase with the increase of M.

4- The minimum blade losses, for the particular blade profile used in this study, were found to be occured at $M=0.6$, so the best efficiency of this blade cascade occurs at this value of flow Mach number.

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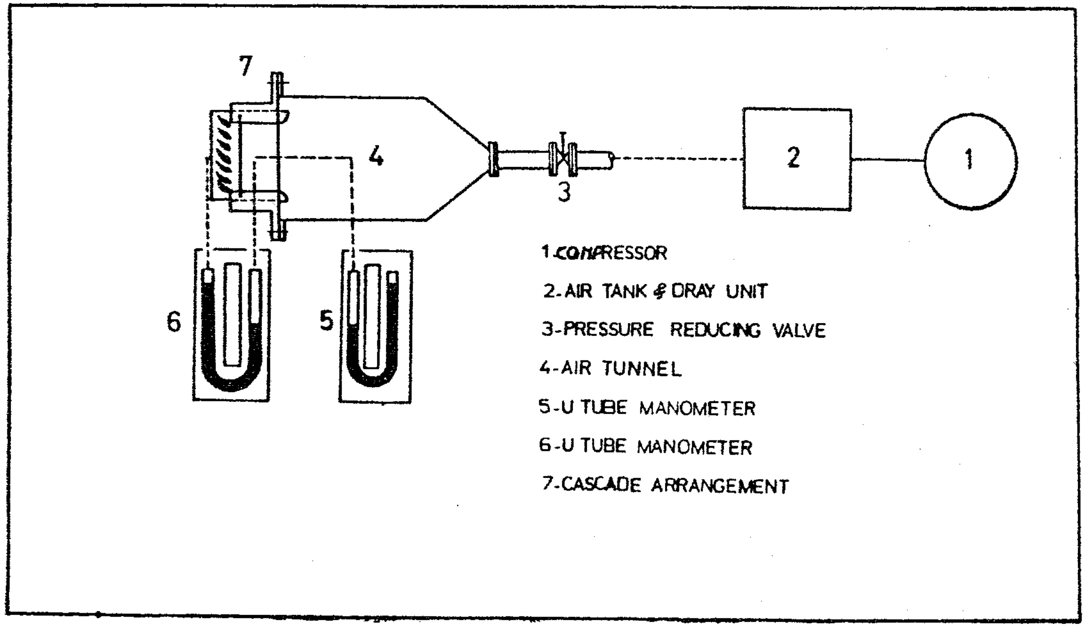

FIG.(1): GENERAL LAYOUT FOR THE EXPERIMENTAL SET.

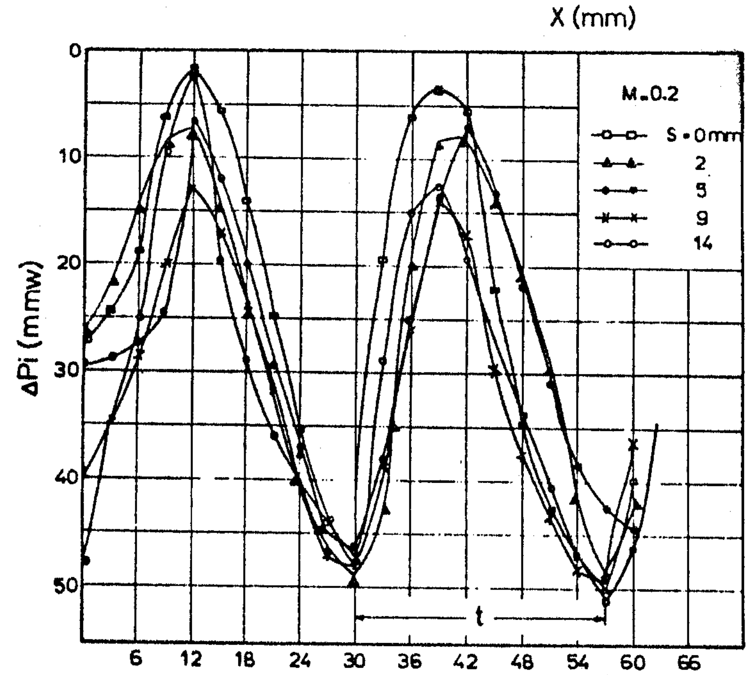

FIG.(2): VARIATION OF THE TOTAL PRESSURE DIFFERENCE (ΔP_i) WITH THE DISTANCE ALONG THE BLADE PITCH (x) FOR DIFFERENT VALUES OF (S).

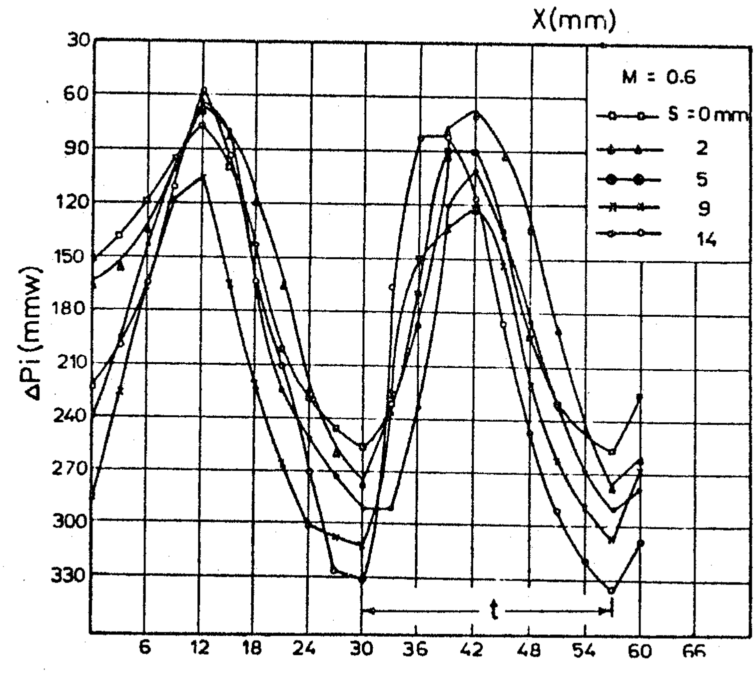

FIG.(3): CONTD.

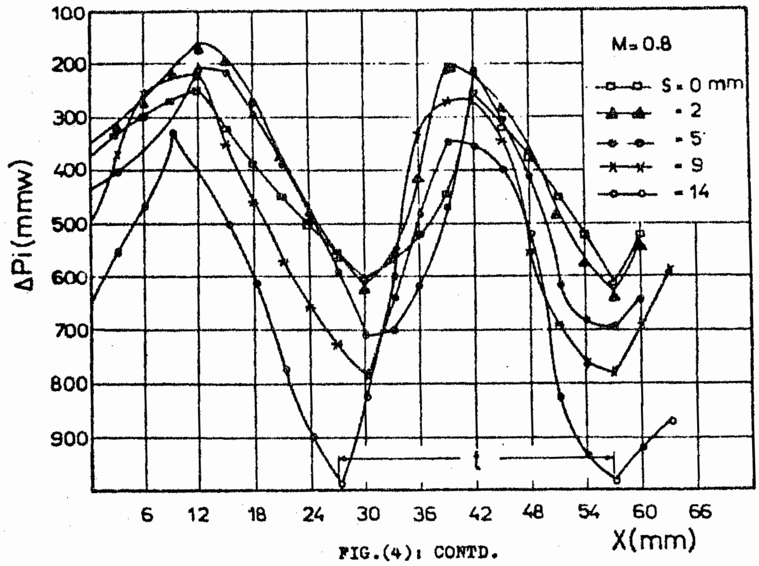

FIG.(4): CONTD.

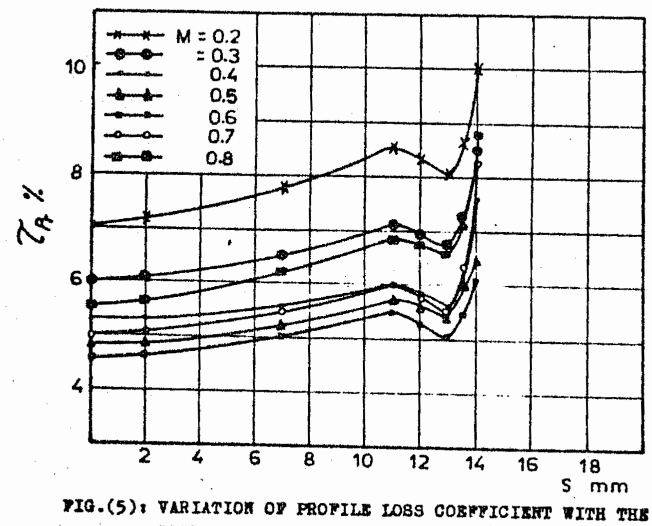

FIG.(5): VARIATION OF PROFILE LOSS COEFFICIENT WITH THE DISTANCE ALONG THE BLADE HEIGHT (S) FOR DIFFERENT VALUES OF (M).

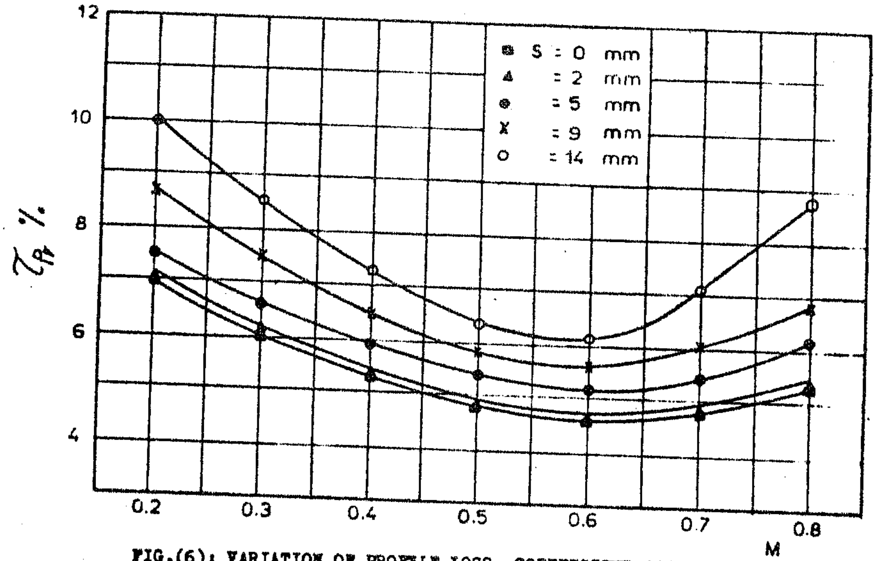

FIG.(6): VARIATION OF PROFILE LOSS COEFFICIENT WITH THE FLOW MACH NUMBER (M) FOR DIFFERENT VALUES OF(S).

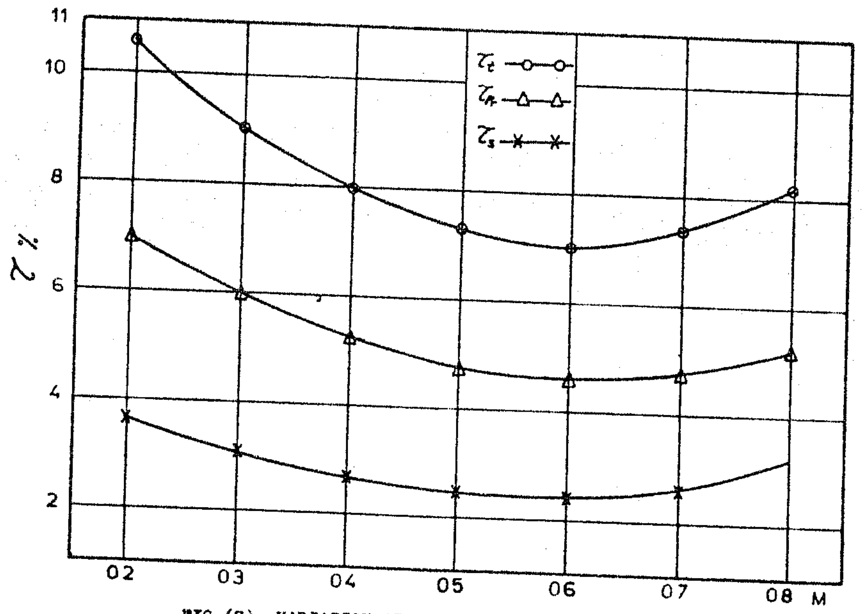

FIG.(7): VARIATION OF THE LOSS COEFFICIENTS WITH THE MACH NUMBER.