AERODYNAMIC CHARACTERSTICS OF CURVATURE BLADE CASCADE

Part II. DYNAMIC CASE

T.I.SABRY*, B.A.KHALIFA*, K.A. IBRAHIM**, and A.ALM ELDEEN***

ABSTRACT:

As an extension to the study of aerodynamic properties of fixed curvature blade cascade in the previous paper, I. static case, by the authors, an experimental investigation has been carried out to establish the effect of the distance between the fixed and moving blades on the characteristics of steam turbines blades. The blade losses are obtained by measuring the total pressure drop across the blade pitch and along the blade height at the end of the trailing edge in the blade cascade. The blade losses were found to depend on both of flow Mach number and the distance between the fixed and moving blades, have smaller values at higher values of these distances. The distance between the fixed and moving blades were chosen to be 1, 1.5, 2, 2.5 and 3 centimeters. A standard fixed blade profile, N(90°-15°), and a standard moving blade profile, M(35°-25°), were used in this investigation, while the flow Mach number was ranged from 0.2 to 0.6.

1. INTRODUCTION:

In order to have an adequate understanding of the performance of turbomachine, an experimental investigation was made on a dynamic model, which simulate a stage of steam turbin consists of fixed curvature blade cascade and moving blades. No experimental work appears to have been carried out and no analysis made in order to investigate the effect of the distance between the fixed and moving blades (i.e. for the dynamic case) on the performance of blades cascade. The effect of flow Mach number ($0.2 < M < 0.8$) and the distance along the blade height on the characteristics of fixed balde without existance on moving blades (i.e. for the static case) has been studied, using an air flow curvature blade cascade by the authors, [1]. The resutls showed that, both of flow Mach number and the distance along the blade height have a significant effect on the blade losses. Cousmetshouv and Prouscouriakov [2], carried out an experimental work on a cascade blade under subsonic flow condition with the object of determining the optimum number of moving blades. They found that the optimum number of moving blades depends on the relative pitch and boundary layer thickness.

Sherstyuk, et.al. [3], found the losses of the first stages of steam turbines with different values of relative height and relative pitch and their dependence on the flow Reynolds number.

---

* Ass. Prof., Mech. Power Eng. Dept., Menoufia University. Egypt.
** Lecturer, Mech. Power Eng. Dept., Menoufia University. Egypt.
*** Engineer, Mech. Power Eng. Dept., Menoufia University. Egypt.

The objectives of the experimental work presented here were ;

1. Obtaining information regarding to the effect of the distance between the fixed and moving blades, L, on the blade losses, the output power of the generator and the speed of rotor at different values of flow Mach number .

2. Determining the effect of the flow Mach number on the blade losses, power of the generator and rotor speed at variable distances between the fixed and moving blades.

3. Obtaining a clear picture about the effect of rotor constant speed on the blade losses.

4. Finding the effect of the disc rotation on the blade losses, at constant distance between the fixed and moving blades, for different values of flow Mach number.

5. Finally, establishing a clear idea about the comparison between the dynamic model, used here, and the static one which has discussed previously and their effects on the turbomachines design.

2. EXPERIMENTAL APPARATUS AND METHODS OF MEASUREMENT:

The experimental set-up used in the experiments is the same apparatus used in the previous part (part I. static case), [1] , except the test section was modified by added the moving blades, which situated in a circular disc mounted on the axis of a Dc-generator, Fig. (1). The disc was mounted on the front of the trailing edges of fixed blades in such away that, the inlet flow angle for the moving blades is equal to 35° and the distance between the fixed and moving blades can be changed from one centimeter to three centimeters. The experimental work was carried out on standard blade profile with constant blade height and setting angle for both fixed and moving blades, blade profile dimensions for fixed N(90°-15°), and moving M(35°-25°) are given by [4] . The following table whows the all profile specifications which were used here.

Profile	Chord mm	Relative height	Relative pitch	Blade Edge thickness	Outlet angle degree	Blade setting angle degree
N(90°-15°)	33.33	1	0.75	1	15	38
M(35°-25°)	24.41	1	0.71	2	25	78

In this experimental work, the following measurements were carried out at different values of Mach number . The stagnation pressure (P_{o1}) before and (P_{o2}) after the cascade and also in the air tunnel were measured by pitot tubes. The total pressure drop ($\Delta p_i = p_{o1} - p_{o2}$) and the other stagnation pressures were available through a U tube manometer. The measurements were taken a long the blade pitch. Measurements of the total pressure loss and the outlet air flow angle are obtained from a traverse along the cascade, using a special meachanism, a short distance downstream of the blades. So the movement distance of the pitot tube can be obtained. The stage output power of the generator and the rotor speed are measured.

The output power (P) is the result of multiplying the volt (V) and the current (I), The volt (V) was measured by a digital voltemeter, while the current (I) was measured by an ammeter. The rotor speed of the disc (n) was measured by a speed-meter in r.p.m.

3. RESULTS AND DISCUSSION:

3.1- Effect Of The Distance Between Fixed And Moving Blades (L) On The Total Pressure Drop:

The total pressure drop (Δp_i) across the blade cascade pitch (t) was found to depend upon the distance between the fixed and moving blades (L). Arepresentative selections of measurements of total pressure drop (Δp_i) along the blade pitch, for different values of Mach number (M) and (L), is given in Figs.(2-4), From these figures it can be deduced that, the maximum value of the total pressure drop occurs at the trailing edge of the blade and has a higher value at a smallest value of the distance, L(L=1 cm) than that at heighest value of L, at (L=3 cm). For the same Mach number used, the figures also indicate that, the variation of (Δp_i) along the cascade pitch have the same trend, and depends upon both of Mach number (M) and the distance (L), where (Δp_i) increases with the increase of (M) and also (Δp_i) increases with the decrease of the distance (L).

3.2- Effect of The Distance Between Fixed And Moving Blades on the Profile Loss Coefficient:

From the previous subsection, the total pressure difference (Δp_i) was found to depend on the distance (L). Therefore, the profile loss coefficient (τ_{pr}) depends also on the values of (L) according to the following equation,

$$\tau_{pr} = \varepsilon^{\frac{k-1}{k}} \cdot \frac{1 - \left[1 - \frac{\Delta p_i}{\Delta p_o}(1-\varepsilon)\right]^{\frac{k-1}{k}}}{\left(1 - \varepsilon^{\frac{k-1}{k}}\right)\left[1 - \frac{\Delta p_i}{\Delta p_o}(1-\varepsilon)\right]^{\frac{k-1}{k}}}$$

Where, $\Delta p_i = p_{o1} - p_{o2}$

$\Delta p_o = p_{o1} - p_2$

$\varepsilon = p_2 / p_{o1}$

p_{o1} and p_{o2} are defined previously, p_2 is the static pressure at cascade outlet and k is the specific heats ratio = C_p/C_v.

Fig.(5) shows the variation of the profile loss coefficient with the Mach number, for different values of (L), the dashed curve shows the results for the case where the case of fixed blade only (i.e. there is no moving blades used). From these curves it is clear that, for each value of (M), (τ_{pr}) increases with the decrease of the distance (L) and for each value of the distance (L), (τ_{pr}) increases with the decrease of (M). This can be explained as, the air flow prior to the moving blade passages, meets with the leading edges of the moving blade profiles, the presence of which causes a disturbance in the flow and increasing of the blade energy losses. This disturbance travelling against the flow, and hence these losses are inversely proportional to the gap between the fixed and moving blades, so the losses increase with the decrease of the distance between the fixed and moving blades. From this figure it can also be seen that, the (τ_{pr}) has a bigger value in the case of existing the moving blades than that for the case of using fixed blades only, (static case).

3.3- Effect Of The Distance Between Fixed And Moving Blades (L) On The Power Of Generator (P):

The output power of the generator was determined according to the relation, (p = V.I watts); The measurements of both of (V) and (I) were taken for different values of (L) and (M). The results are shown in Fig. (6). From this figure, it can be deduced that, for each value of (L), the output power (P) increases with the decrease of the distance (L). Fig. (7) shows the variation of the output power (P) with (L), for different values of (M) at constant speed of rotor (n = 1500 r.p.m). A comparison between the results illustrated in Fig. (6), where the rotor has a variable speed ($n \neq$ conts.), with those in Fig. (7), where the rotor has a constant speed (n = const.), indicates that, the output power, for each values of (L) or (M), has a higher values in the case of ($n \neq$ const.) than that in the case of (n = const.).

3.4- Effect Of The Distance Between Fixed And Moving Blades (L) On The Rotor Speed (n):

Fig.(8) shows the variation of the rotor speed (n) with the distance between the fixed and moving blades (L). for different values of (M) and for the generator is loaded (i.e the field current (I) is adjusted at rated value by the variavle resistance). Fig.(9) shows this variation with the flow Mach number for the case of the generator is not loaded. From these figures it can be seen that, for each value of (M), the speed of rotor (n) increases with the decrease of the distance (L) and also, for each value of (L), the speed of the rotor (n) increases with the increase of (M). This may be due to that, the speed of rotor is proportional to the air velocity at the fixed blade exit. So the decrease of output power and the speed of rotor with the increase of the gap between fixed and moving blades (L) is thought to be a result of two factors: the first of them is that the nonhomogenious flow field behind the fixed cascade. The flow field becomes more homogenious due to turbulent mixing for the case of large value of (L). This is always accompanied by a loss of Mechanical energy. The second reason is that, the increase of the gap (L) leads to increase of fluid portion escaping from the moving blades this is based on the stretching of free jets.

3.5- The Total, Profile, and Secondary Loss Coefficients At Constant Distance Between Fixed And Moving Blades at (L = 1 cm):

The results are shown in Figs (10-11). The total loss coefficient (τ_t) in Fig. (11), was determined from Fig(10) by counting the area under each curve, where M=const., the secondary loss coefficient (τ_s), Fig.(11), was calculated by subtracted the value of ((τ_{pr}) at (S = 0) from the total loss coefficient at each value of (M) used.Fig.(11) indicates a comparison between the three coefficients, τ_t, τ_{pr} and τ_s , for L = 1 cm. For each value of (M), the total loss coefficient curve has a heighest values than the other loss coefficients. Also from this figure it can be seen that, the loss coefficients decrease with the increase of Mach number (M).

3.6- The Profile Loss Coefficient At ($S = 0$; $L = 1$ cm) For Different Values of The Rotor Speed (n):

Fig. (12) indicates the variation of the profile loss coefficient with the Mach number (M), for L=1 cm and S=0 (i.e the measurements were taken at the mid height of the blade). The dashed and dotted curve represents this variation when the generator is not loaded. While the dashed curve represents this variation for the case where the generator is loaded. The other three curves are for n=1000, 2000 and 3000 r.p.m. From this figure it can be seen that, for each value of (n) (τ_{pr}) decreases with the increase of (M), while for each value of (M), (τ_{pr}) decreases with the increase in the value of (n). This can be explained, for constant values of M and L, as an increase of the rotor speed (n), the flow resistance through the moving blades increases and the pressure increases in the gap between the fixed and moving blades, this leads to a decrease of pressure drop on the fixed blades and hence a decrease in the profile loss coefficient.

4. CONCLUSION:

The following conclusions can be drawn from the previous discussion.

1. The total pressure difference across the cascade pitch, the profile loss coefficient, the output power of the generator and the rotor speed were found, for each Mach number used, to increase with the decrease of the distance between fixed and moving blades. While, for each distance between fixed and moving blades, the output power and the speed of the rotor were found to increase with the increase of Mach number. At constant rotor speed, the same effect was obtained. Also, for the case of generator is not loaded, the rotor speed has the same effects like those when the generator is loaded.

2. At constant distance between fixed and moving blades, the profile loss, the secondary loss and the total loss coefficients were found to decrease with the increase of Mach number.

3. The profile loss coefficient was found to decrease with the increase of Mach number at constant rotor speed, and also was found to depend on the generator whether it is loaded or not.

4. A comparison between the results in the case of existing the moving blades with that where no moving blades exist (usual cascade) demonstrate that, the profile loss, secondary loss and total loss coefficients have a higher values, in the case of moving blades exist, than those obtained from the usual cascade, and these values were found to depend on the values of distance between the fixed and moving blades, L, and the flow Mach number, M. For example, for M=0.6, the profile loss coefficient increases by about 62% at L=1 cm and by about 23% at L=3 cm, the secondary loss coefficient increases by about 46% at L=1 cm, and the total loss coefficient increases by about 38% at L=1 cm. While for M=0.2, the profile loss coefficient increases by about 81%, the secondary loss coefficient increases by about 72%, and the total loss coefficient increases by about 79%.

5. This study indicates that, the assumption which, previously, has been used by previous investigators for using the results obtained from a fixed blade cascade in the turbomachines design is not well correct. Therefore, the effect of the moving blades on the performance of curvature blade cascade must be taken in the consideration.

REFERENCES:

1. Sabry, T.I., Khalifa, B.A., Ibrahim, K.A. and Alm Eldeen, A. "Aerodynamic characterestics of curvature blade cascade", Part I. static case Eng. Research Bull., Faculty of Eng., Menoufia Univ., Vol. 5 , 1982.

2. Cousmetshouv, R.V. and Prouscouriakov, G.V. "The effect of relative pitch of moving blades on the characterstics of turbostages ", Thermal Eng. J., December, 1974.

3. Sherstyuk, A.N., Sokolov, A.I. and Smiknov, G.A., " Investigation of fixed blades of axial turbines with low relative height of blades ", Thermal Eng. J., June, 1982.

4. Deuch, M.E., et.al., "Atlas of profiles for steam and gas turbines ", Moscow, 1965.

5.T T. I. SABRY, B.A. KHALIFA ,K.A. IBRAHIM ,&A. ALM ELDEEN,
AERODYNAMIC CHARACTERISTICS OF CURVARE BLADE CASCADE.
ENG. RES.BULL. ,FACUL. ofENG. & TEC. ,MENOUFIA UNIV.
Vol V Part 1 ,1983. pp(117-126)

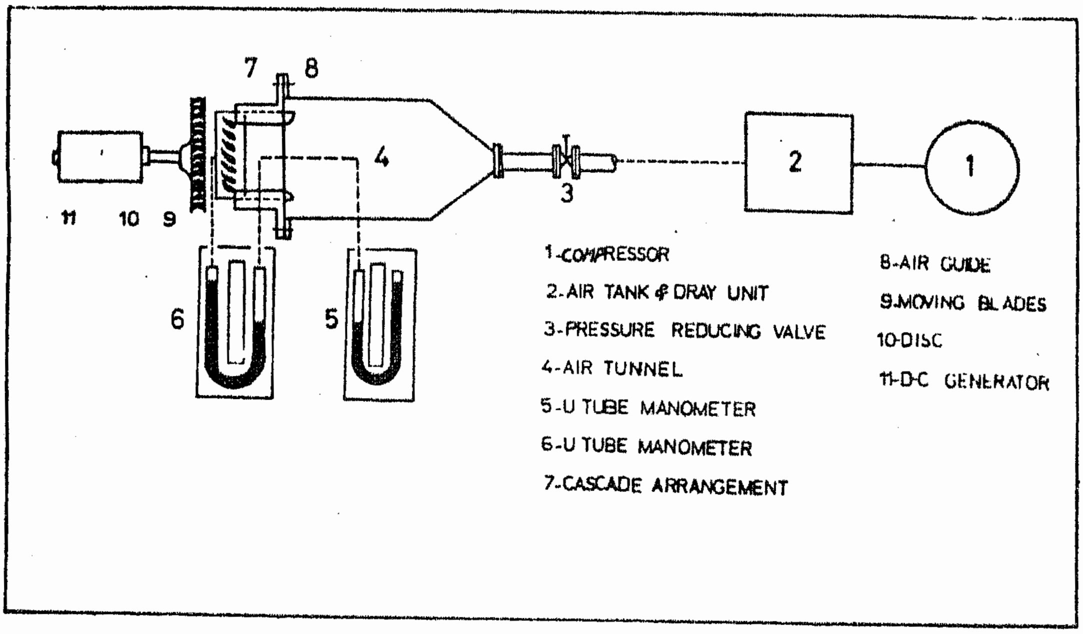

FIG.(1): GENERAL LAYOUT FOR THE EXPERIMENTAL SET.

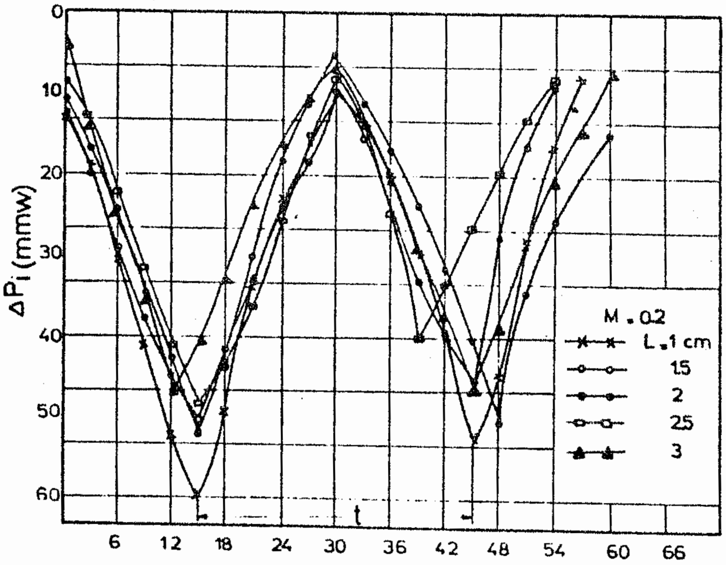

FIG.(2): VARIATION OF THE TOTAL PRESSURE DROP (ΔP_i) WITH THE DISTANCE ALONG THE CASCADE PITCH (X) FOR DIFFERENT VALUES OF (L).

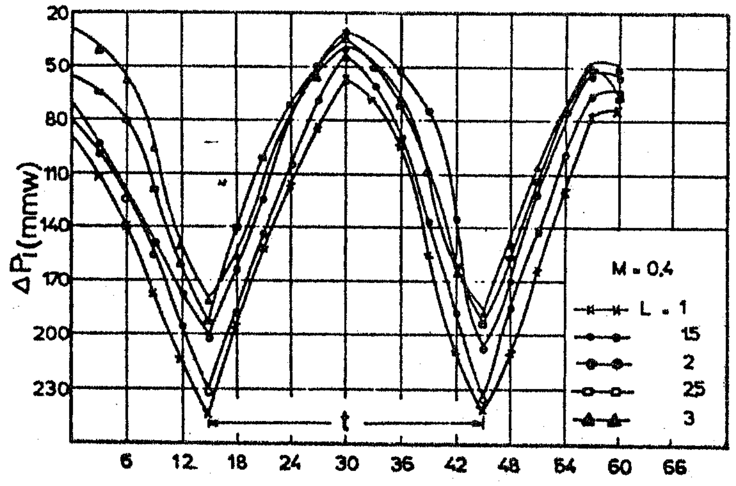

FIG.(5): CONTD.

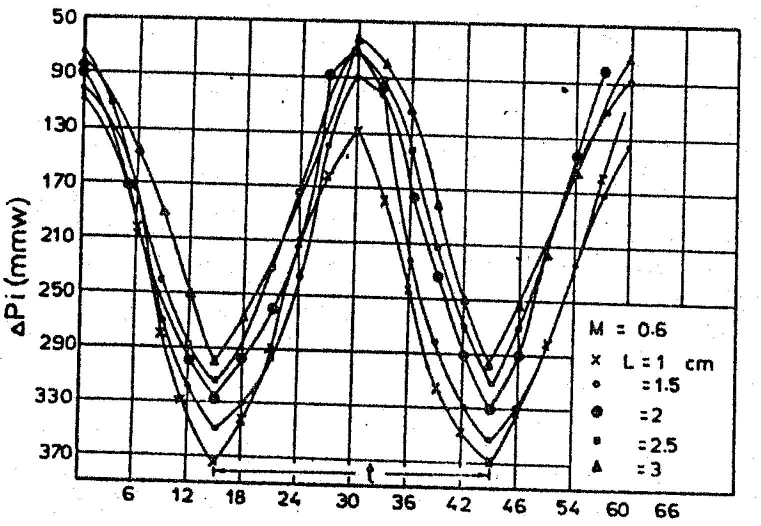

FIG.(4): CONTD.

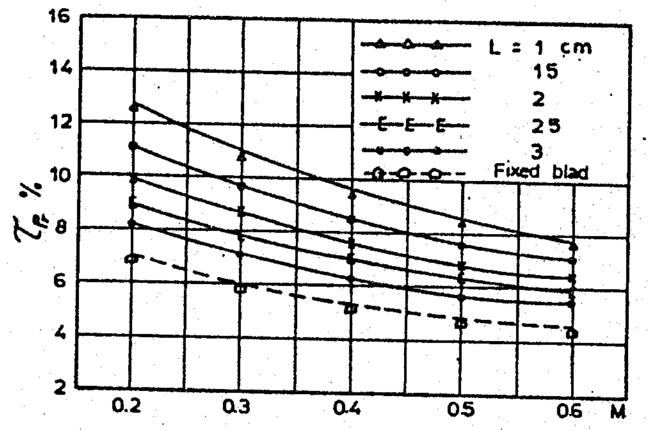

FIG.(5): VARIATION OF THE PROFILE LOSS COEFFICIENT (τ_{pr}) WITH THE MACH NUMBER (M) FOR DIFFERENT VALUES OF THE DISTANCE BETWEEN THE FIXED AND THE MOVING BLADES (L).

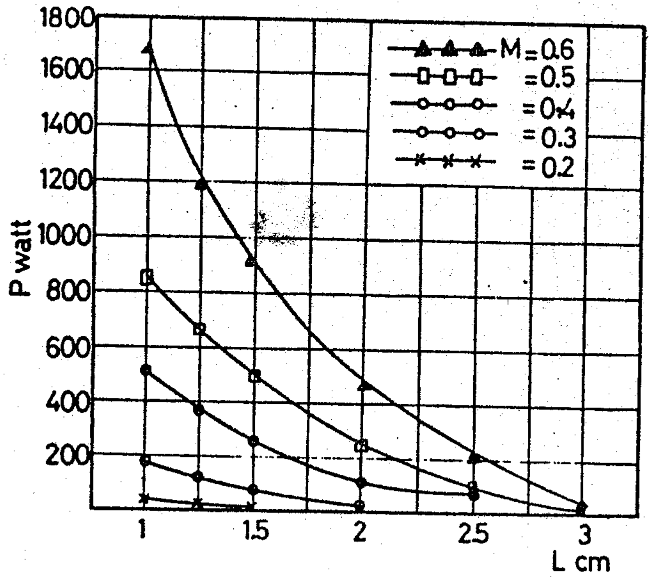

FIG.(6): VARIATION OF THE GENERATOR POWER (P) WITH THE DISTANCE BETWEEN THE FIXED AND THE MOVING BLADES (L) FOR DIFFERENT VALUES OF (M).

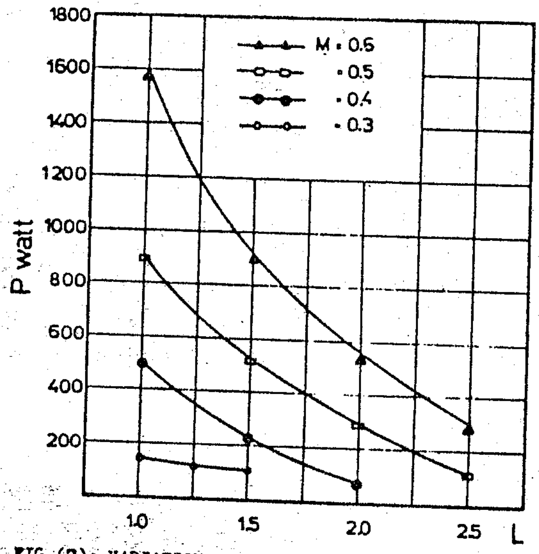

FIG.(7): VARIATION OF THE OUTPUT POWER WITH THE DISTANCE (L), FOR DIFFERENT VALUES OF (M) AND FOR n = 1500 r.p.m.

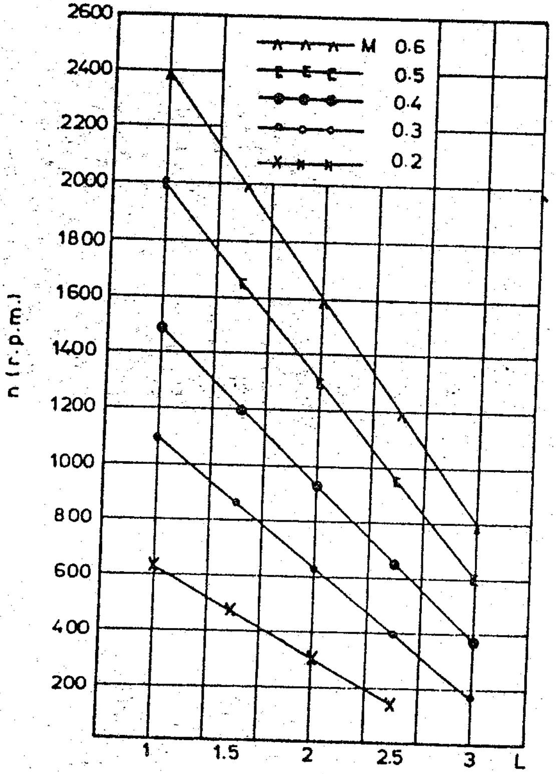

FIG.(8): VARIATION OF THE ROTOR SPEED (n) WITH THE DISTANCE (L), FOR DIFFERENT VALUES OF (M). (GENERATOR IS LOADED).

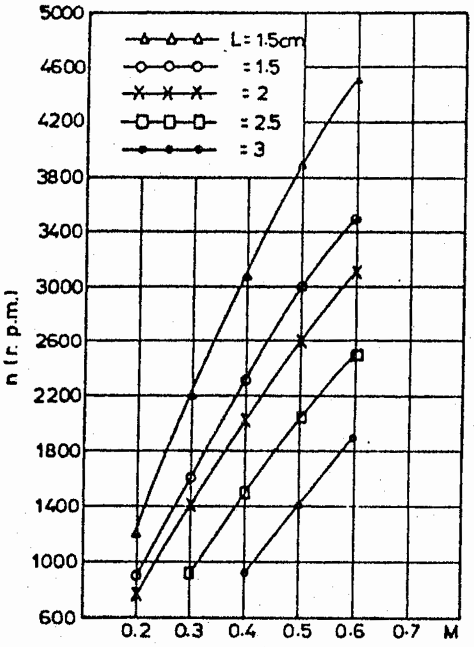

FIG.(9): VARIATION OF THE ROTOR SPEED (n) WITH THE DISTANCE (L).(GENERATOR IS NOT LOADED).

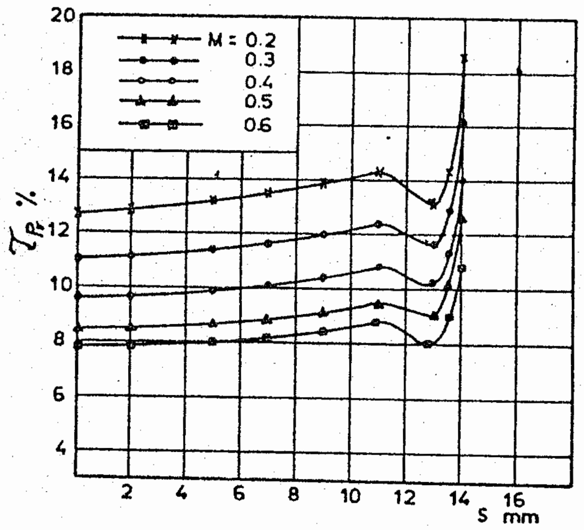

FIG.(10): VARIATION OF THE PROFILE LOSS COEFFICIENT (τ_{pr}) WITH THE DISTANCE ALONG THE BLADE HEIGHTS(S), FOR DIFFERENT VALUES OF (M) AND FOR L = 1 Cm.

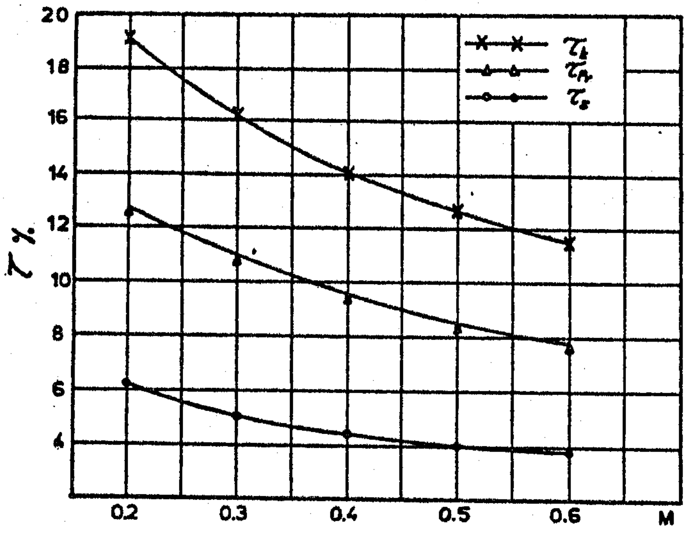

FIG.(11): VARIATION OF THE LOSS COEFFICIENTS WITH MACH NUMBER (M), FOR (L = 1 Cm).

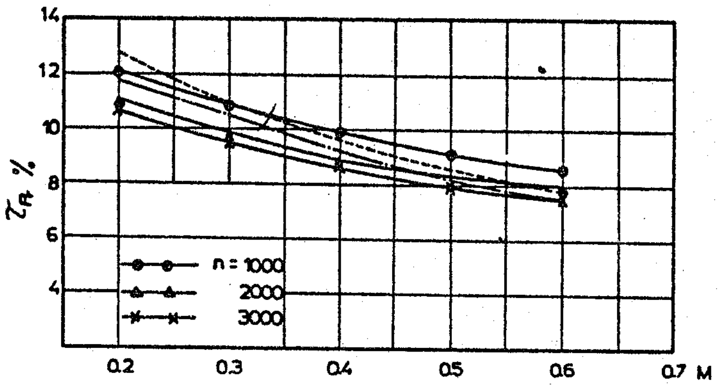

FIG.(12): VARIATION OF THE PROFILE LOSS COEFFICIENT (τ_{p_r}) WITH THE MACH NUMBER (M) FOR (L= 1 Cm AND δ = 0).