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Determination of influence of internal surface roughness of a fan rotor onto its performance parameters

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Abstract

Computional fluid dynamics study and experimental test using the standard methods on flow characteristics of the centrifugal fan, have been presented in this paper. This investigation was performed to determine the influence of internal surface roughness of fan rotor onto its performance parameters. The testing results are presented in form of graphs showing the efficiency, pressure and power in function of flow.

Keywords: Centrifugal fans; CFD simulation; Fan performance prediction; Surface roughness of rotor

1 Introduction

Numerical simulation is more and more often used in modern technologies of the thermal fluid flow machine improvement. Although thermal processes and wavy motion phenomena does not occur in centrifugal fans, mathematical modeling and numerical simulations of simple flow phenomena in fan rim and spiral collector are very essential. Use of these methods for determination of flow structure in rotor, calculation of the pressure increase and loses within chosen elements, which in contradistinction to rotor effective work are not so easy measurable with use of analog techniques allow to verify analytic and numerical models in any sections of the fan rim and housing.

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By using a commercial code packets, supported by our own balance results considered as boundary conditions, there were imaged structural elements and studied variability of boundary conditions for operation of various fan grade. Relatively precise flow velocity profiles within interblade channels, static pressure increase on rotor and flow structures [2, 4, 5], have been determined. Author of the present study was inspired with the testing results shown in Figs. 1 and 2, and decided to introduce artificial roughness onto passive surface of blades in vicinity of high flow velocities in order to 'turbulize' interblade flows using relatively coarse-grained abrasive papers. In result a research project aimed at the influence of the rotor internal surface roughness on the fan energetic performance has been developed.

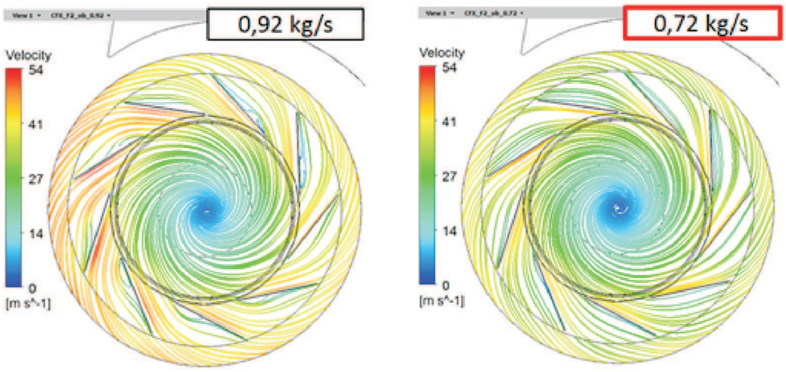

Figure 1. Vortex structures in the interblade passages.

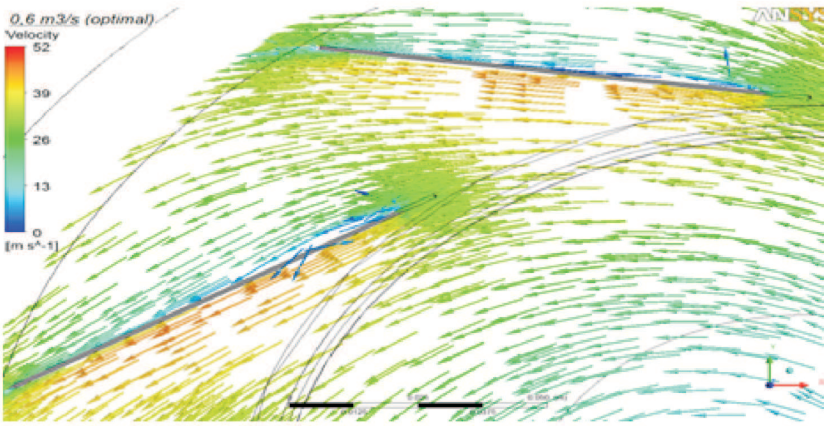

Figure 2. The inflow on the passively side of vane of rotor as shown in Fig. 3 for optimal point.

Examination of the influence of the roughness onto performance of low-pressure fluid flow machines was aimed at the determination of the fun efficiency. Full fun characteristics were determined in balance experiment. They are very useful for the analysis of all loses occurring in the fun, according to monograph [1].

The roughness first of all influences the friction loses, which in optimal point constitute 25% of total loses. The friction loses are reduced with the flow drop. However, volumetric loses, flow loses in collector and back-flow loses are increased. Thus continuation of analytic works on methods of calculation of flow characteristics for given geometry is needed, what is named as solution of simple problem or analysis. However, the influence of the roughness should be included into the procedure mentioned above.

Influence of the roughness understood as nondirectional geometrical structure on the fun efficiency, pressure rise and power of radial bladed rotor working in free space or in space limited with spiral collector, have been examined in the presented research project. Three models of radial bladed rotors having optimal geometry with respect to rotor and housing geometry as well as smooth surface, have been examined. Roughness was changed in two models, in which passive blade surfaces (first stage of the rotor surface covering) and active blade surfaces (II covering stage) as well as frontal and rear rotor wall (III covering stage) were covered with P40 abrasive paper in the first model and P80 abrasive paper in the second model.

After three blade covering stages and flow tests each rotor was covered with abrasive paper on its whole internal surface. Third rotor model was smooth and made of welded steel. For rotor and housing, the model measured surface roughness height (Ra) amounted for $Ra = 5$. For abrasive paper P80 the surface roughness height amounted for $Ra = 40$ and for paper P40 of the greater roughness the height amounted for $Ra = 80$ [3]. Rotors with artificial roughness and smooth rotor are shown in Fig. 3.

The rotors were also examined in free space. The space was limited with standard spiral housing of dimensions matched to pressure flange AxB. Condition of the targeted surface roughness essentially influences rotor flow performance. It was proved by the results of examination of rough and smooth rotors without housing, which are shown in Figs. 5–7 as well as by results of examinations of housed rotors shown in Fig. 8–10.

2 Result of the influence of the internal rotor roughness influence on a rotor without housing

Although thickness of the abrasive paper glued onto the surface reduces rotor geometrical dimensions (width) as compared with smooth what results in flow

Figure 3. On the foreground the rotor with P40 sandpaper is show, second one is with P80 sandpaper, last one is smooth.

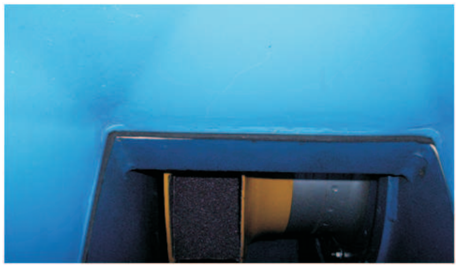

Figure 4. The smooth housing which was used for testing rotors with artificial roughness.

parameters change, as observed for a case of increased grain-size of abrasive papers from P80 into P40 – no change of the rotor width – the maximal efficiency is reduced from 56% to 51% only in result of the surface roughness change. Efficiency drop is decreased from 70% to 60% when the rotor works in housing. The efficiency and pressure rise are reduced.

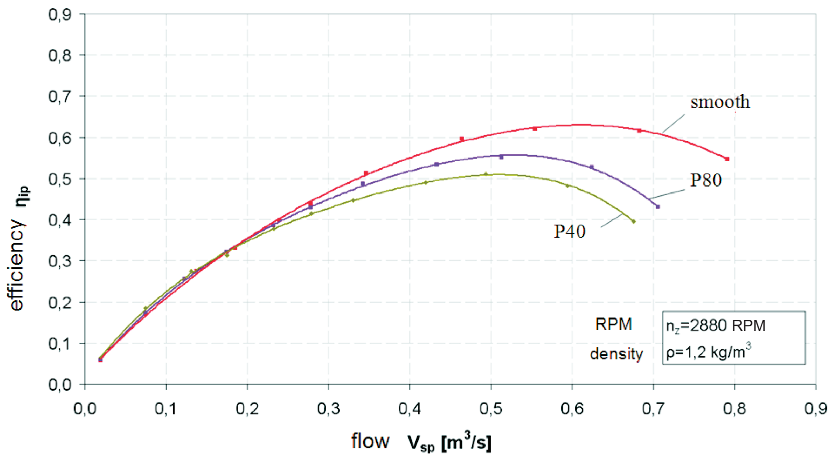

Figure 5. The influence of artificial roughness achieved by using abrasive papers P40 and P80 on the inner surfaces of the rotor, on the internal efficiency and comparison of the efficiency of the smooth rotor tested in the free space.

In result of the rotor gluing with abrasive paper its width is reduced with 2 mm. Influence of this geometrical parameter change on flow parameters is negligibly small and is located between smooth rotor (first on the top) and P30 curve (second on the top) shown in Fig. 5. However, between curves P80 and P40 surface roughness is essential without greater influence of the rotor width.

3 Result of the rotor roughness influence on a housed rotor

Results of the housed rotor roughness examination are show in Figs. 6–8.

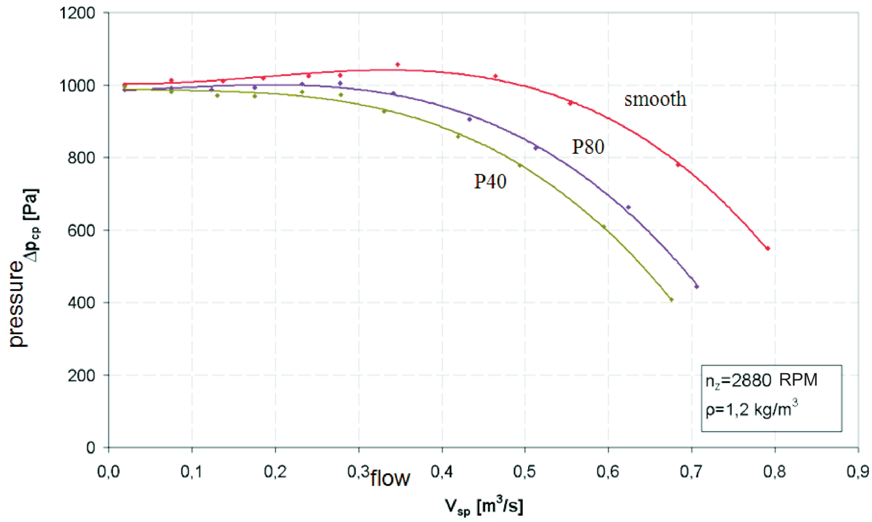

Figure 6. Influence of P40 and P80 roughness located on the inner surfaces of the rotors on the pressure compared with the pressure of the smooth rotor, tested in the free space.

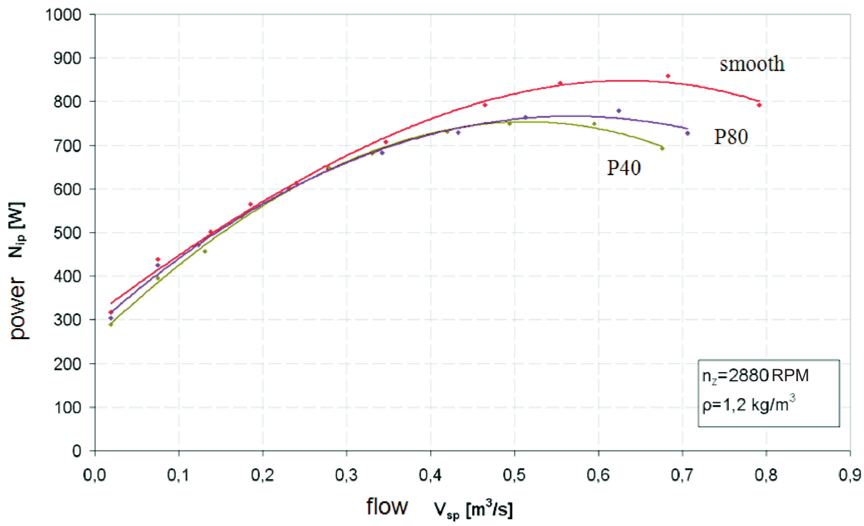

Figure 7. Influence of P40 and P80 roughness located on the inner surfaces of the rotors on the power compared with the power of the smooth rotor, tested in the free space.

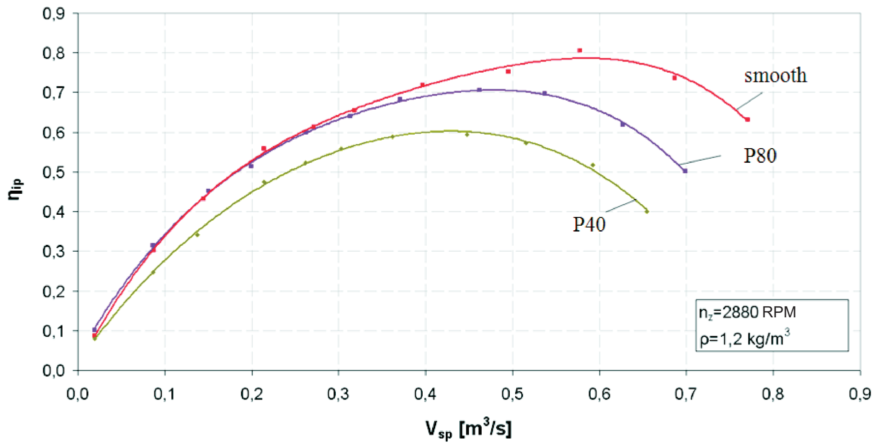

Figure 8. Influence of P40 and P80 roughness located on the inner surfaces of the rotors on the internal efficiency and comparison with the internal efficiency of the smooth rotor, tested in the housing.

4 Result of the roughness influence of chosen housed rotor surfaces

Trial of the explanation of the role of artificial roughness of passive side of rotor blades and whole surface of rotor blades, has been executed. The needed roughness was obtained by using abrasive paper P40. Metal sheet from which the rotor housing was made and smooth rotor have natural roughness.

Influence of passive side onto rotor efficiency is show in Fig. 9. Increase of the roughness area with passive side of the rotor blade resulted in the rotor efficiency improvement, including small pressure rise within measuring error range, as shown in Fig. 8 as well as rise of internal power, as shown in Fig. 9. Thus we can conclude that increase of the surface roughness at both sides of the rotor blades results in the fun performance reduction but much more essential as was expected the influence of the passive side. Results of the experiment do not answer a question what could happen if the active blade side worked with its smooth passive side. Such roughness configuration could give other results than those obtained in experiments, which are shown in Fig. 9. However, such examinations were not executed because in such case additional and not planned rotor model is needed what rises the cost of the examinations. Such option should be considered in further examinations.

Roughness of the whole rotor internal surface decreases efficiency even more that only roughness at both blade sides. Efficiency is reduced from 68% to 60%.

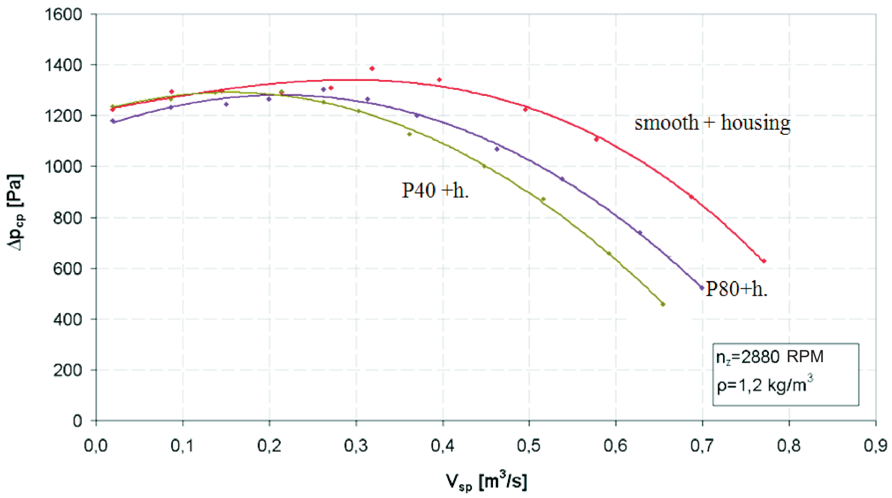

Figure 9. Influence of the roughness of the same rotors on the pressure and comparison with the pressure of the smooth rotor, tested in the housing.

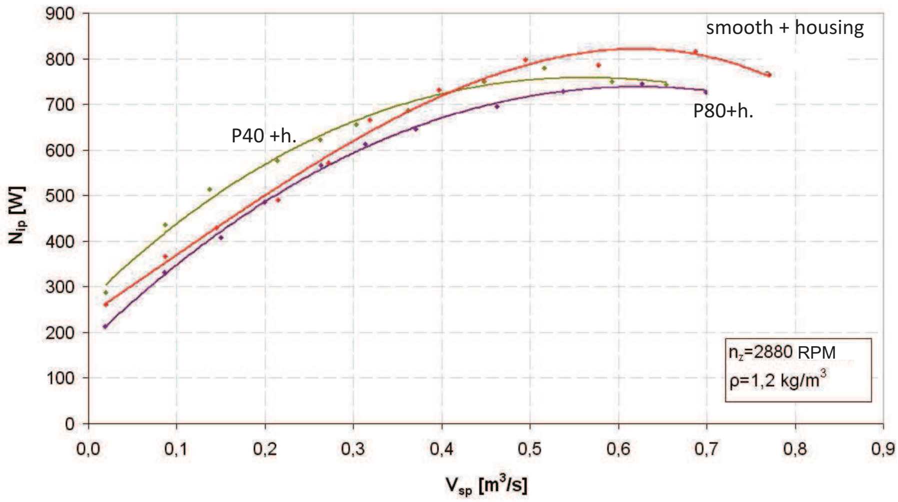

Figure 10. Influence of the roughness of the same rotors on the power and comparison with the power of the smooth rotor, tested in the housing.

5 Summary of the roughness examination.

Relations between roughness height Ra and rotor efficiency has been described by Ackeret's formula which can be rearranged into a form allowing the exponent X calculation:

$$1 - \eta_i = (1 - \eta_i^o)\Big[0.5 + 0.5\big(\tfrac{Ra^o}{Ra}\big)^X\Big] \,,$$

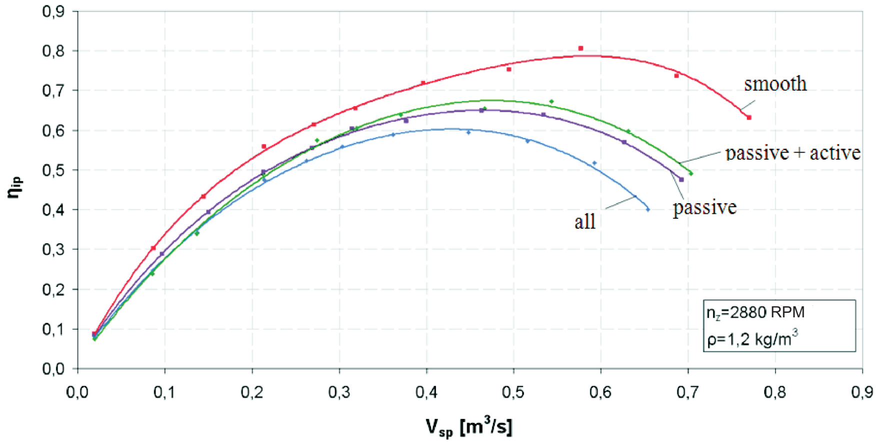

Figure 11. Influence of surface roughness of paper P40 laid on the inner surfaces of the rotor and on the passive and active sides of the blades, on the internal efficiency and comparison with the internal efficiency of the smooth rotor, tested in the housing.

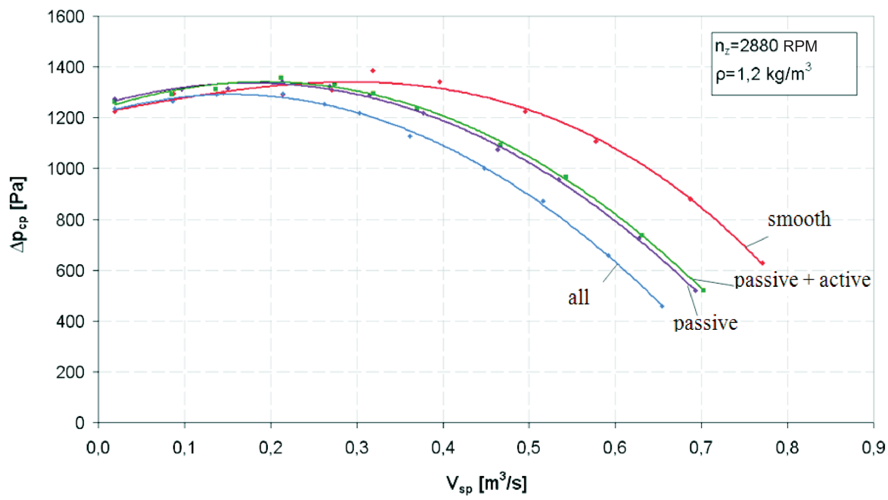

Figure 12. Influence of surface roughness of paper P40 laid on the inner surfaces of the rotor blades (discs and blades of the suction and discharge sides), on the pressure and comparison with the pressure of the smooth rotor, tested in the housing.

$$\frac{1-\eta_i}{1-\eta_i^o} - 0.5 = 0.5\Big(\frac{Ra^o}{Ra}\Big)^X, \tag{1}$$

$$a = b^X,$$

$$X = \tfrac{\ln a}{\ln b},$$

where: Ra^o – set roughness, Ra – reference roughness, η_i^o – set efficiency.

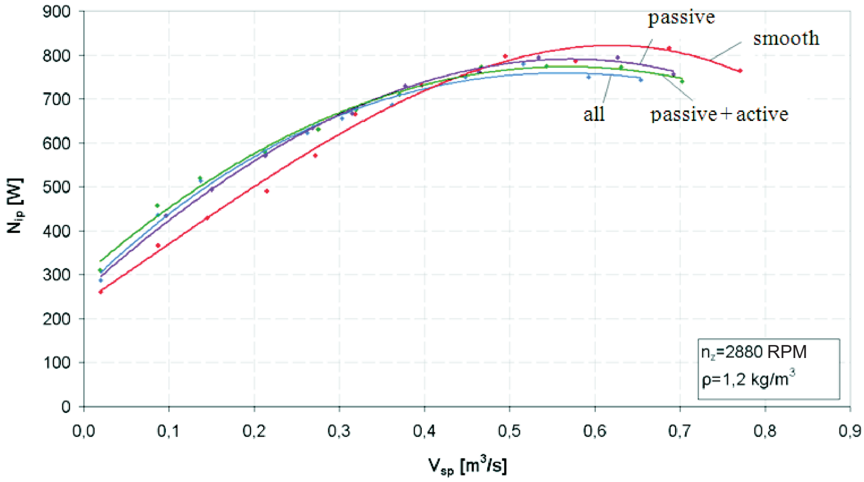

Figure 13. Influence of surface roughness of paper P40 laid on the inner surfaces of the rotor and both sides of the blades, on the power and comparison with the power of the smooth rotor, tested in the housing.

Based on the testing results value of the component X – for housed rotor and X^* – for rotor without housing, have been determined.

Efficiencies for smooth rotor ($Ra = 5$) and rough rotor ($Ra = 40$ and $Ra = 80$) values are shown in column 1 and 4 of Tab. 1.

Table 1. Table of values of for tested fan roughness.

1	2	3	4	5	6
η_i	Ra	X	η_i^*	Ra^*	X^*
0.79	5	-0.26	0.63	5	-0.16
0.70	40	-0.36	0.56	40	-0.18
0.60	80	-0.79	0.51	80	-0.25

The roughness has bigger influence onto flow parameters in case of the rotor operation in limited space rather than in free space. Flow loses are greater and efficiencies are lower than in case of housed rotor operation. Exponent X of Ackeret's formula has arithmetic mean value of about (-0.2). In conditions of housed rotor operation averaging of the value of the exponent X is not possible. Roughness of the passive blade side has great and disadvantageous influence of the rotor efficiency, which is considerably reduced.

Rotor efficiencies from Figs. 5–8 rearranged according to formula (1) into conditions mentioned in legend after substitution of exponents X or X^* from Tab. 1 are shown in Figs. 14 and 15. Diagrams marked wit dotted line prove usability of Ackeret's formula for determination of the rotor efficiency in roughness function.

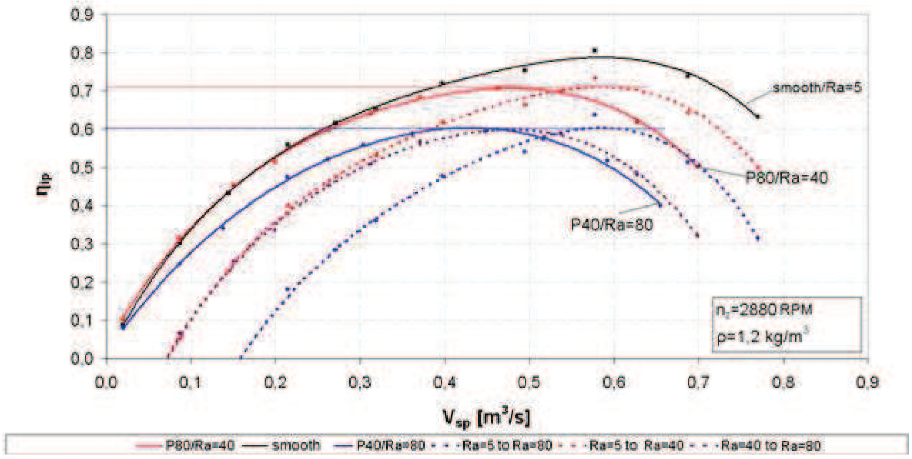

Figure 14. Recalculated characteristics of the the efficiency of the rotor (in housing) from experimental graphs for variable roughness.

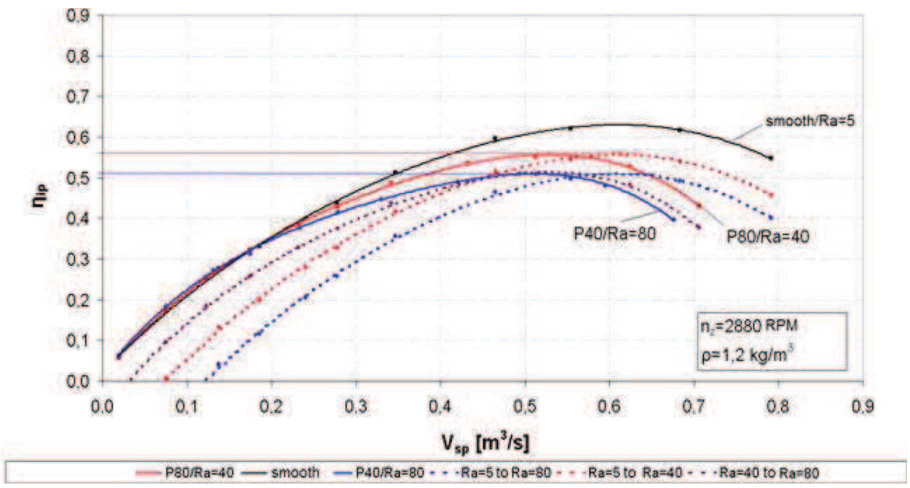

Figure 15. Recalculated characteristics of the the efficiency of the rotor (without housing) from experimental graphs for variable roughness.

6 Conclusions

The roughness has greater influence onto flow parameters in case of the rotor operation in limited space rather than in free space because the static efficiency applied in free space not take into account the dynamic energy.

Roughness of the whole rotor internal surface decreases efficiency even more that only roughness at both blade sides.

The roughness of active side add to roughness of passively side of blade operate beneficially at efficiency. The double-sided roughness of blades reduce the friction losses in comparison to single-sided roughness of passively side. Then flow losses be lesser and efficiency be taller. It is not known how single-side roughness affect on active blade side.

Exponent X of Ackeret's formula takes the arithmetic average value about (-0.2). In conditions of housed rotor operation averaging of the value of the exponent X is not possible. The results of recalculated demonstrate the usefulness of Ackeret's formula into determine efficiency in function of roughness.

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