COOLING OF ELECTRICAL MOTORS

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SUMMARY

The cooling of an induction motor using a reversible radial impeller is investigated numerically and experimentally by measuring the volume flow and motor temperature. The influence of different design parameters (diameters, blade geometry) of the impeller is assessed. The most influential design parameter for cooling efficiency is the impeller diameter.

INTRODUCTION

The cooling of electrical machines and motors is of great importance: As the temperature of the electrical components sinks, the lifespan is extending. In addition, by improving the cooling the overall efficiency of an electric drive is improved. With the requirements for energy efficiency of drives continuously rising, the influence of the cooling efficiency has to be taken into account.

The induction motor is of great importance and one of the greatest user of electric energy. The cooling of these motors is by a radial impeller with straight radial blades, as the cooling performance should be independent of the sense of rotation. In addition the impeller should be cheap and robust. The overall dimensions of the motors are fixed, thus limiting the available space for the impeller.

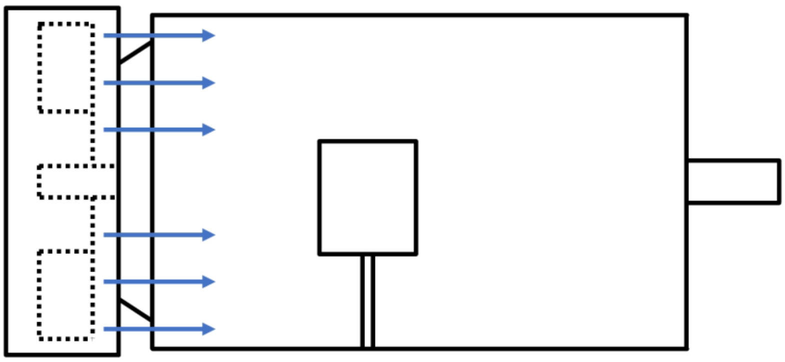

Figure 1: Motor cooled by external fan

The impeller is fixed on the non-drive end of the shaft. The air enters in axial direction through a protective grid in the fan cover, it is moved in radial direction by the rotating impeller, it exits the impeller, it is diverted by the fan housing in axial direction and finally exits through a gap between fan housing and motor casing (in axial direction) in order to cool the fins of the motor casing.

A great variety of impellers are used: there are different number, sizes and shapes of the straight radial blades which are mounted on a base plate. The base plate may also come in different shapes and sizes. In addition, there are also many variations in the design of the fan cover which influences the flow after it leaves the impeller.

Data in the literature about the design of these impellers is scarce. The set-up of models for the cooling or the acoustic performance is described. Using computational fluid dynamics, an optimization for a specific configuration is performed, [2], [3], [5]. For specific configuration, measurements are reported and some hints for enhancing the cooling performance are given. Recently the performance of radial impellers is compared to the performance of axial impeller [1], [4]. Consistently the impeller diameter is an influential design parameter. With regard to the impellers used for motor cooling, the great variety of designs is remarkable.

In order to shed light into the performance of these different impeller designs, a comparative investigation is performed, to identify the features of an impeller geometry which might enhance the motor cooling efficiency.

APPROACH

A motor was arbitrarily chosen, to perform an exemplary investigation: induction motor, 2 pole, rated power 1.3 kW, energy efficiency IE2, size 80. Different geometries for radial impeller and fan cover were investigated in order to identify the most significant design parameters for the efficiency of the radial impeller and to improve the motor cooling.

In experimental setups, the volume flow rate generated by the impeller as well as the motor temperature due to different efficiencies in cooling were investigated. Different commercial available impellers, as shown in table 1, as well as own designs produced by rapid prototyping were tested. These results may also be used for other motor types and sizes under the condition of geometric similarity and similar Reynolds numbers.

In a first step the performance of different commercial available impellers is tested, [5], [6]. Using these results the cooling efficiency, characteristics of the impeller design and shape are identified, which enhance the cooling efficiency. Then the influence of these characteristics on the cooling efficiency is investigated, [6], [7]. In addition the influence of additional parameters, derived from the analysis of the flow patterns, is identified.

Table 1 : Commercially available impellers tested: MV80 R, 80/13-01, 137-11, VTB80, CV80, diameter and blade number

	**80/13-01**	**115 mm**	**5**
	**CV 80**	**145 mm**	**6**
	**132-11**	**132 mm**	**12**
	**VTB 80**	**142 mm**	**12**
	**MV 80R**	**145 mm**	**12**

New impeller designs, as shown in figure 2, are derived from this analysis. These new designs are then realized using a 3D printer. Based on these results an optimization of the impeller geometry is possible.

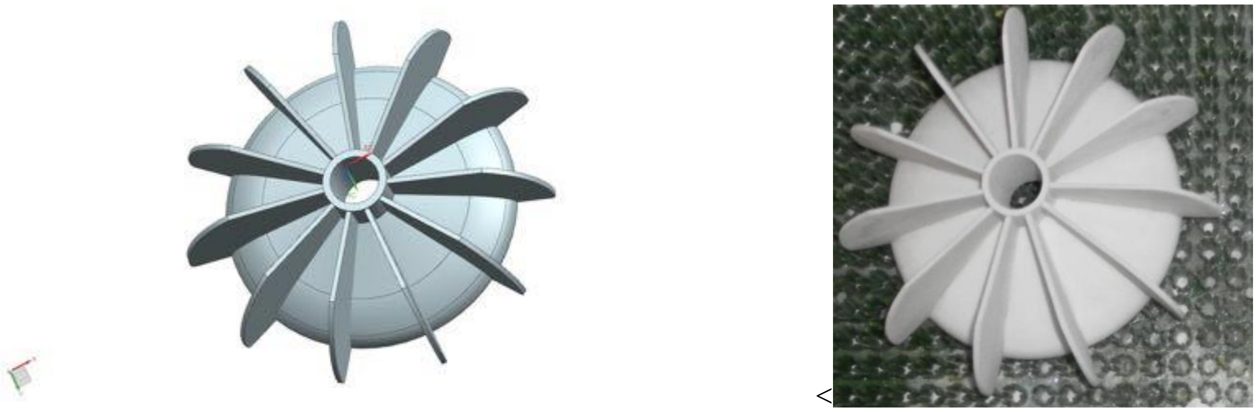

*Figure 2: Optimized impeller LR11 (diameter 153,5mm and 11 blades) CAD-drawing (left)
3-D printed specimen (right)*

In this investigation the variable geometric parameters are geometry, shape and size of the impeller, with the restriction that the impeller is reversible, i.e. straight radial blades. The geometry of the motor casing and the fan cover are fixed. The inner diameter of the fan cover is 155 mm.

In order to assess the motor cooling the volume flow rate of the impeller as well as the motor temperature were determined in these investigations. Acoustic aspects are not addressed in this analysis. Nevertheless a fan with a bad efficiency will most certainly also cause acoustic problems. Thus analyzing and optimizing in terms of cooling efficiency also implicitly helps to reduce the noise level.

METHODOLOGY

Volume flow measurement

The volume flow rate of the impeller inside the housing is determined using a test airway following dimensions specified in DIN 24163, figure 3. The test specimen consists of the impeller (driven by the motor shaft), the fan housing with the inlet and the outlet as the gap between fan housing and motor casing. The motor is connected and works with maximum speed to maximize the volume flow. The test rig is carefully sealed.

Figure 3: Test airway for volume flow measurement, [6]

The inflow is from the surroundings. The motor is mounted in a flow chamber, so that the flow exiting the gap between housing and casing enters directly the chamber. The flow exits the chamber and the volume flow is measured by a thin plate orifice. The volume flow rate of interest is for a zero pressure difference between inlet and outlet, i.e. surroundings and chamber. Thus a secondary fan with variable speed drive is needed to compensate for the flow losses through the test airway.

The speed of this secondary fan is adjusted until the excess pressure in the chamber is zero. As the volume flow rate of the impeller is relatively small, great care has to be taken in the experimental set up and execution.

Temperature measurement

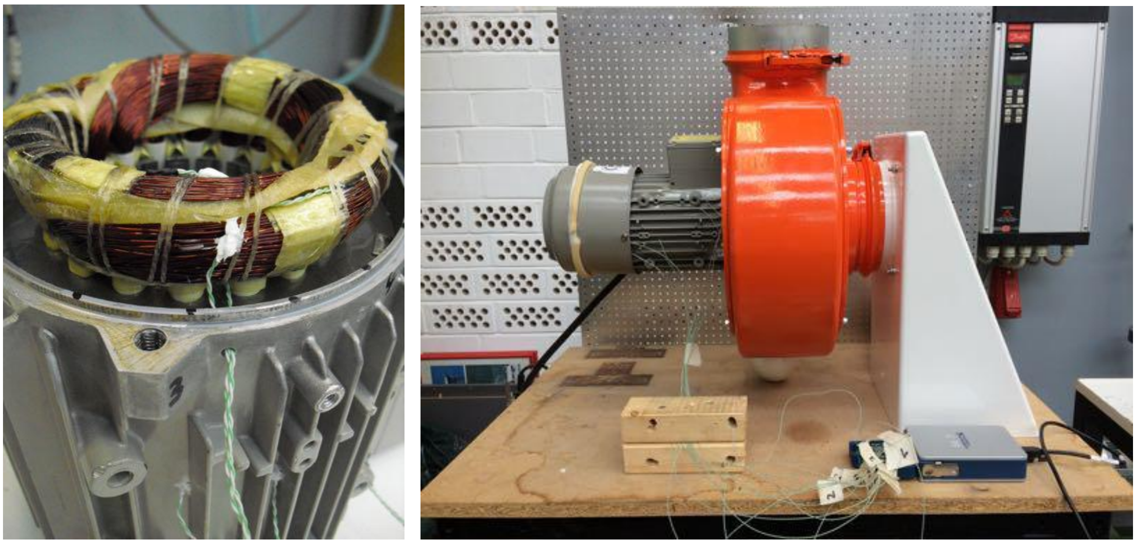

Figure 4: Test rig for temperature measurement. Motor with thermocouples on the winding (left). Temperature measurement for motor working as a fan drive (right), [7].

Thermocouples are fixed at different positions in the windings and the casing of the motor, figure 4. The motor is then operated with a load until steady conditions are reached and the measured temperature do not change any more. Then the temperature difference to the (measured) ambient temperature is determined. In this way the cooling efficiency of different impeller designs can be assessed. The temperature rise of the windings is approximately 100 K, the temperature rise of the casing is approximately 45 K.

RESULTS

The commercially available impeller, table 1, cover a wide range of different geometries and have significant differences in the cooling efficiency, [6], [7].

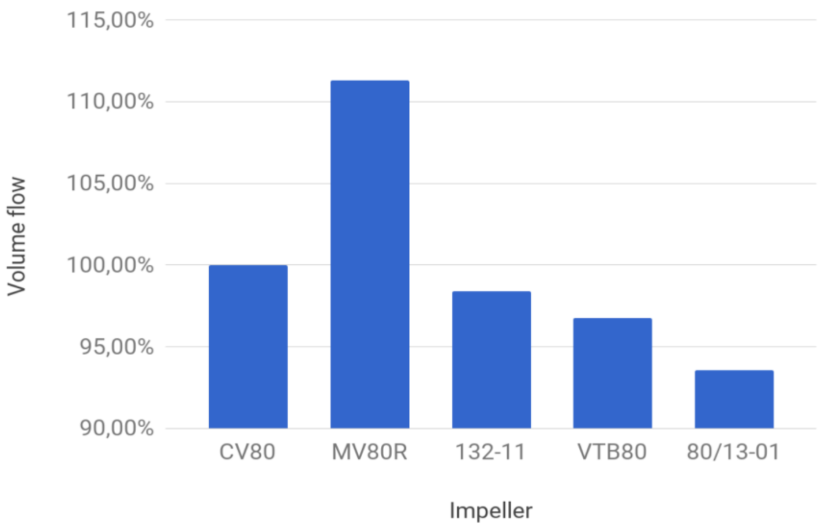

Figure 5: Comparison of volume flow rate for motor cooling with different impeller types

With regard to the volume flow there are considerable differences in the fan performance as shown in figure 5: As expected the biggest volume flow is for a big impeller with many blades the smallest volume flow for a small impeller with few blades.

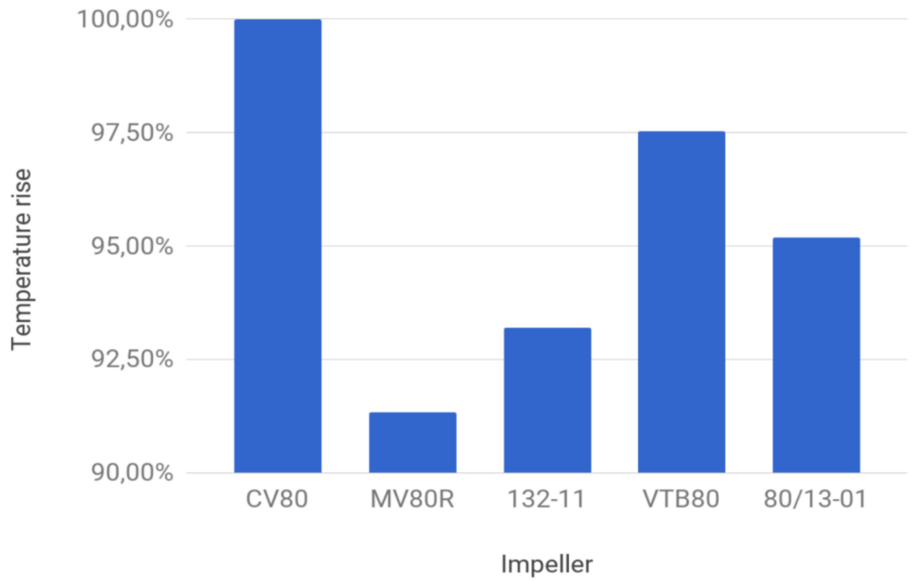

Figure 6: Comparison of temperature rise for cooled motor with different impeller types

As with the volume flow there are significant differences in the cooling performance of the impellers, figure 6. The best cooling is achieved by the impeller with the maximum volume flow. Nevertheless the results indicate (see VTB80 figure 5 and figure 6) that there are additional factors (i.e. dimension of base plate, turbulence, swirl) that influence the cooling efficiency.

Starting from this analysis new impeller geometries were derived and investigated by changing only one geometric parameter, [7], [8]. Thus main characteristics that influence the cooling efficiency were identified:

Impeller diameter

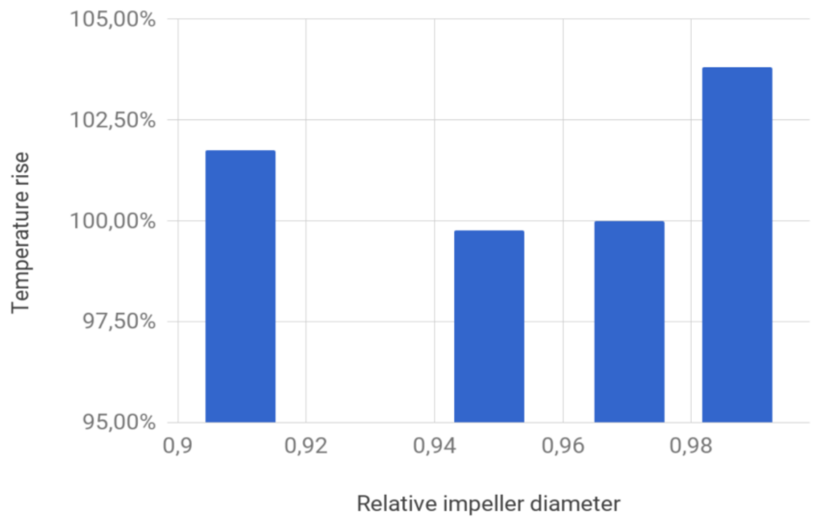

Figure 7: Influence of impeller diameter LR 11 on temperature rise for cooled motor. The impeller diameter is scaled by the inner diameter of the cover.

The most influential parameter is the impeller diameter, figure 7: with increasing diameter the fan performance increases. Increasing the diameter decreases the space between impeller and fan cover. The flow exiting the impeller gets choked, so that the additional performance due to an increase in impeller diameter is diminished by the choking effects. In terms of maximizing the cooling effect the impeller diameter should be maximized. In terms of energy efficiency and low noise level a smaller diameter is desirable.

Blade number

Figure 8: LR-type impellers with different blade numbers

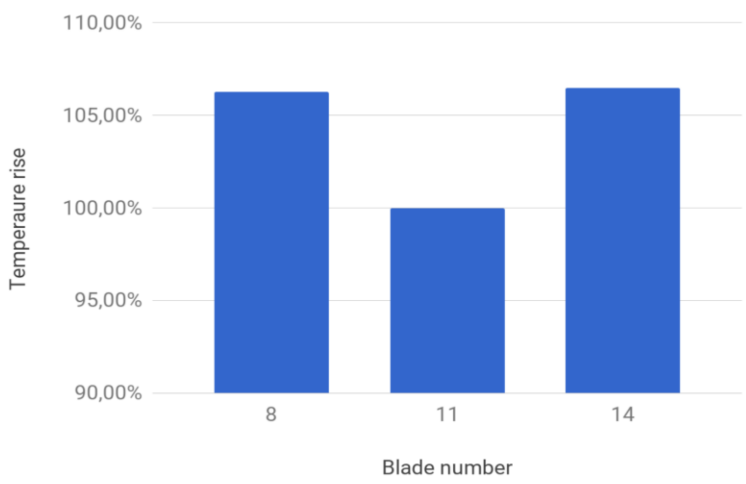

Figure 9: Influence of blade number on temperature rise for cooled motor.

Good results can be achieved by blade numbers between 8 -14, figure 9. For LR-type impellers the best cooling effect was for 11 blades. If the number of the blades is significantly lower, the volume flow cannot be maintained and in addition secondary flow patterns in the flow channel between the blades evolve. If the blade number is significantly higher the obstruction of the flow path by the blades in the inflow cross section gets significant.

Blade thickness

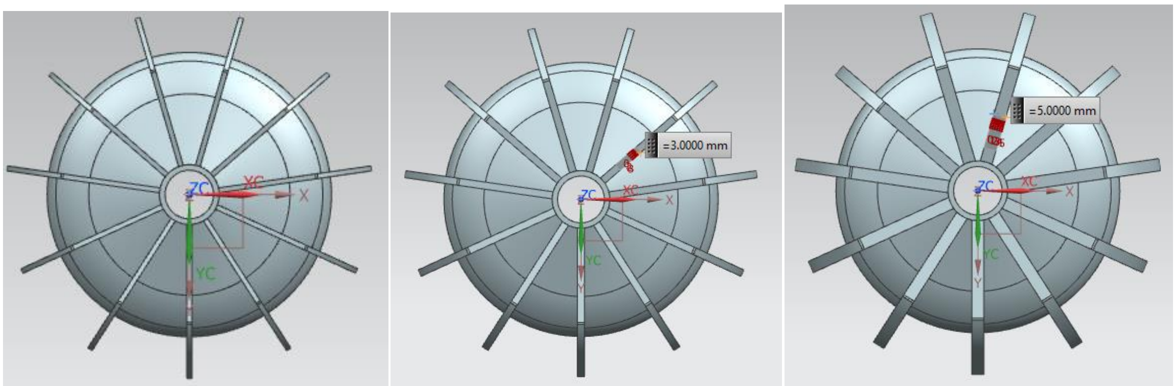

Figure 10: LR-11 impellers with different blade thickness

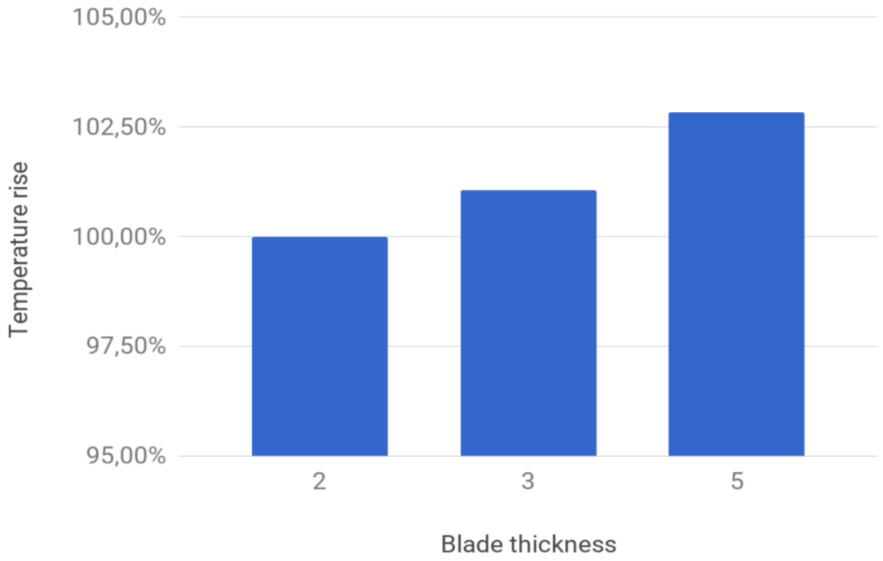

Figure 11: Influence of blade thickness on temperature rise for cooled motor. Blade thickness in millimeters.

The ideal blade has no thickness at all. Due to the manufacturing process, e.g. plastic casting, a definite thickness has to be realized. For the configuration tested, significant limitations in the cooling performance were observed for a thickness bigger than 3 mm.

Blade area

Figure 12: LR-11 impellers with different blade height

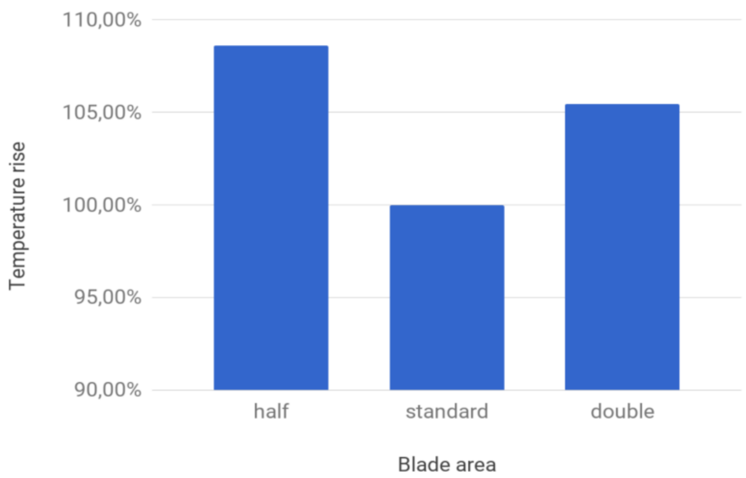

Figure 13: Influence of blade area on temperature rise for cooled motor

Increasing the blade area has a positive effect on the cooling efficiency: The higher the blades the better the cooling. The blade height is limited by the available space inside the fan cover. If the area and thus volume of the blade in the inflow area is too big, obstruction occurs and the inflow and thus the cooling is limited.

Material / surface roughness

The surface roughness has a slight negative effect on the cooling efficiency. The impellers from 3 D-printing with an unprocessed surface had consistently a slightly inferior cooling performance then the geometrical similar (commercially available) plastic impellers. For industrially produced impellers with a finished surfce this is of minor importance.

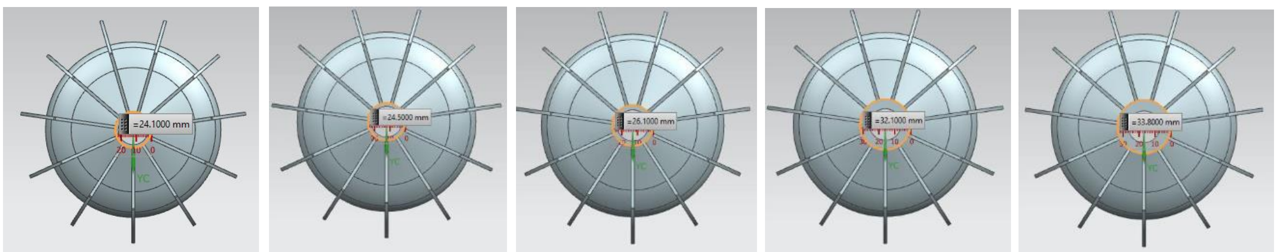

Figure 10: LR-11 impellers with different hub diameters

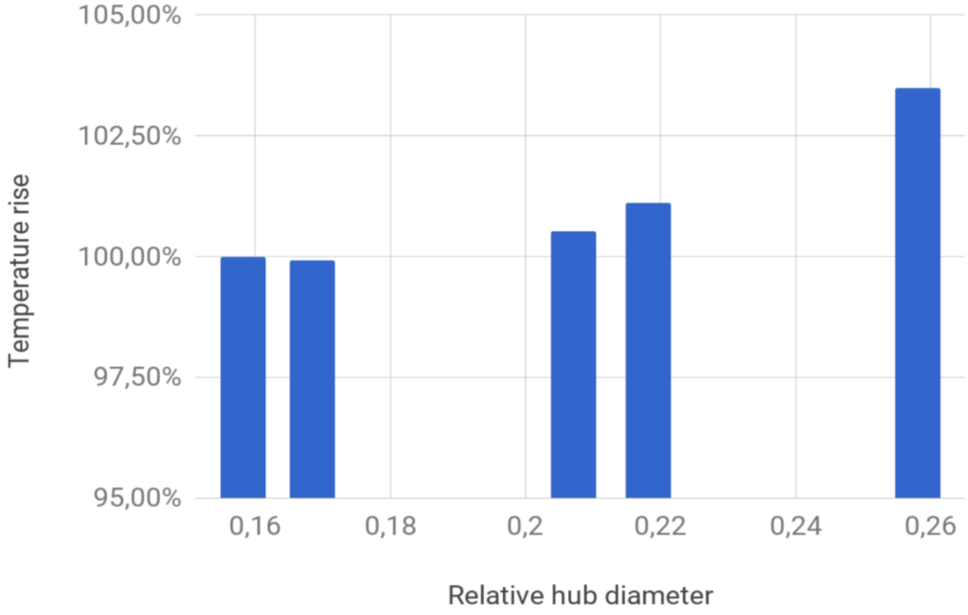

Figure 15: Influence of hub diameter on temperature rise for cooled motor. The hub diameter is scaled by the inner diameter of the casing

Shape of the base plate

In general the shape of the base plate does not influence significantly the cooling efficiency. Nevertheless it is important to avoid obstruction in the inflow area, for example by an oversized hub as shown in figure 14 and figure 15. Obstructions constrain the inflow and lead to a diminishing cooling efficiency.

Based on this analysis the original impeller was optimized achieving an increase in cooling efficiency (difference of temperature) of 10%: The diameter was maximized, the blade number is 11 and the obstruction in the inflow area minimized, figure 2. With regard to the geometrical parameters considered no further enhancement was possible. Nevertheless there are still parameters (i.e. base plate diameter, inner diameter blade) which could be considered and could be influential.

CONCLUSION

Using these results it is possible to optimize the design of radial impellers used for cooling motors and drives. As the analysis was performed using temperature measurements of the cooled motor and volume flow measurements with coinciding results, the results obtained should be reliable. As a method, the measurements of the temperature rise seems more efficient, due to the simplicity of the installation and execution.

Due to the blade thickness and surface roughness there are small differences in the volume flow and temperature rise for the industrial available impellers and the impellers from 3D printing. Nevertheless the trends are similar. Thus an optimization might be performed with prototypes from 3D printing, significantly decreasing the demanded effort.

The changes of many design parameters often seemed to have only a minor effect, as the impeller is only one part of the cooling device and the design of the fan cover is of similar importance. One critical design parameters for the motor cooling is the gap between impeller and fan cover and the gap between fan cover and motor casing as the flow gets choked in these areas thus strongly reducing the cooling efficiency of the arrangement. An efficient optimization of the motor cooling has to involve the redesign of the fan cover and motor casing as well, in order to achieve a significant increase in the cooling efficiency.

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