Operation and sound power characteristics of cooling fans in surrounding structures

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This paper gives a view of means to design a low noise cooling fan for applications, where cooling has a significant role regarding the operation of the machine. The measures have been divided into three parts and are based on the specific sound power level of the fan. The study concentrates on the noise generation of fans in cooling applications and how to design a system, which generates as little noise as possible

Noise legislation and customer demands have lead to a situation where noise is becoming more and more important when designing new machinery and equipment. In order to perform reliably, many machinery applications require cooling. The cooling system however has effects on the total performance of the machine. In some applications the power consumption of the cooling system can be a considerable proportion of the power of the whole machine. In many cases the sound power of the cooling system determines the total sound power of the machine. By careful design it is possible to reduce the power consumption and noise generation of the cooling system.[1]

For reliable operation cooling must be arranged in machinery and equipment such as electronics, compressors, engines and motors used in various applications. Normally cooling is provided by a cooling fan. The type of fan arrangement is dependent on the actual application, where space restrictions, cooling requirements and system resistances play a significant role when designing the cooling arrangement. Some configurations for example include heat exchangers, some applications must be provided with enclosures. Many factors in the system can toughen the requirements of the cooling fans in the form of system resistance.

The results of the experimental work applied in this study have been done in a surrounding environment of a cooling fan in an induction machine application, but can be to some extent applied to other type of cooling purposes where fans are the primary source of noise.

The test set up and measurements

The performance of the cooling fans in this study were tested in an induction machine mock up. The mock up was constructed to represent the surroundings of the cooling fan as far as airflow and the structures close to the impeller are concerned. A photograph of the machine mock up in figure 1 shows that the mock up actually consisted of a proper machine casing. The fan cover was constructed so that the studied installation parameters could be adjusted fairly easily. The installation parameters included the positioning of the impeller in the inlet shroud, different shroud shapes and lengths and impeller tip clearances. Also a number of different fan types and impeller dimensions could be installed in the surrounding structures quite easily.

Fig. 1: The mock up.

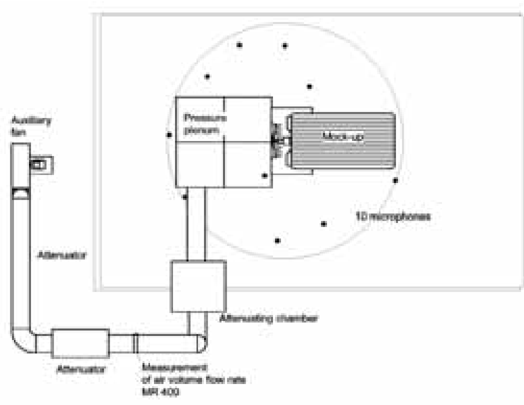

Fig. 2: The test set up

To get a wider perspective of the performance of the fan, its performance was tested at several operating points i.e. at various system resistances. In order to vary the operation point an air supply system was introduced to the cooling fan section set up. The air supply arrangement consisted of a pressure plenum at the suction side of the cooling fan and ductworks leading from the auxiliary fan to the plenum. A schematic drawing of the arrangement is shown in figure 2. The auxiliary fan was used to overcome the pressure losses of the ductworks and also to vary the system resistance in order to get results at various operation points of the fan.

The air volume flow was measured using a measurement ring installed in the ductworks. The pressure rise of the fan was measured as the pressure difference between the pressure plenum and the fan cover. Therefore the results describe the performance of the impeller in its surroundings. The sound power was determined by the pressure method described in standard ISO 3744[2]. The measurements were carried out applying the method according to standard ISO 10302[3]. In this case the airflow exceeded the standards recommendations. The deviation was handled by increasing the dimensions of the pressure plenum. The sound power of the cooling system was measured simultaneously with the aerodynamic performance in a semi-anechoic chamber.

The formulation of the results

The volume flow q (m^3/s) and the pressure rise Δp (Pa) of the fan are expressed as the commonly used dimensionless coefficients i.e. the flow coefficient φ and pressure coefficient ψ, respectively. These are defined in equations 1 and 2.

$$\varphi = \frac{4 \Diamond q}{\pi \Diamond d_2^2 \Diamond u_2} \qquad \psi = \frac{2 \Diamond \Delta p}{\rho \Diamond u_2^2} \qquad (1,2)$$

where d_2 (m) is the impeller diameter, u_2 (m/s) the peripheral speed of the impeller at the outer diameter, and ρ (kg/m^3) the density of air. The specific sound power L_{W0} of a fan is expressed in the following equation:

$$L_{WT} = L_{W0} + 10 \Diamond \log \frac{q}{q_0} + 20 \Diamond \log \frac{\Delta p}{\Delta p_0} \qquad (3)$$

where q_0 is $1 m^3/s$ and Δp_0 1 Pa. L_{WT} is the total sound power level.

The equation of the specific sound power level of a fan is based on fan laws and the dependency between the sound power of the fan and the performance of the fan which are determined by the cooling requirements and structure. The harder the requirements are, the higher the sound power level of the fan is bound to be.

Most of the results are presented as performance and specific sound power level curves of the fans. The curves are presented as a function of the flow coefficient and show the changes when the operation point of the fan is shifted. Some results on the other hand concentrate only in the variations of the sound power results at a certain operation point.

Means of affectng fan noise in cooling applications and relating results of experimental work

According to the specific sound power level approach, the fan noise level, just as power consumption, is dependent on the airflow rate and pressure rise of the fan. The dependency on the pressure rise however differs. The sound power generated by the fan is influenced by the cooling requirements themselves and if possible should be considered first designing a cooling system.
The nature of the airflow system gives boundary conditions to the selection of the fan. For different airflow - pressure rise ratios different type of fans should be applied. Basically, for steeper system resistance curves the dimensioning of the fan should lead to the selection of a centrifugal fan, for lower system resistances the choice should be an axial flow fan. To some extent the surrounding structures and other possible requirements can lead to exceptions to the design rules. Different type of fans have different specific sound power levels both at the best operating point and along the whole sound power curve as a function of airflow rate, as has been pointed out in earlier research by for instance Neise[4]. Also the aerodynamic design of blades and impellers has an effect on the specific sound power of the fan.

Apart from the right fan type selection an important factor is to get the flow resistance curve match the best operating point of the fan. Depending on the fan type and application the difference can be up to 10 dB between the best and the worst operation points. The changes in noise are due to the changes of aerodynamic conditions in the impeller cascade and cannot be avoided, if the operation point lies far from the best operation point, for instance in the stalling region.
Although the design of the cooling requirements and fan dimensioning had been carried out in the best possible manner, there are other aspects that can affect both the performance and noise generation of the fan. This can be realised by studying the specific sound power levels of the fan arrangement. Whether the levels exceed the ones determined for different fan types it can be assumed that the sound characteristics could be improved by one means or another. Some structures in the vicinity of the fan and therefore influencing the fan noise generation mechanisms must be avoided in order to achieve the final right cooling solution.

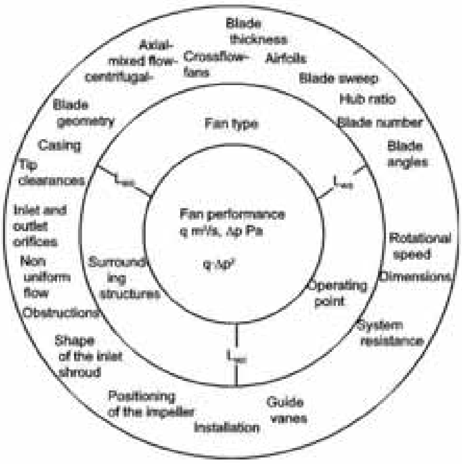

Fig. 3: Factors affecting cooling fan noise

Figure 3 gives an overview of the factors to be taken into consideration when designing a low noise cooling application. It is also good to bear in mind that in the case of having to use additional noise control measures, such as sound attenuators, it is important not to affect the above mentioned factors.

Specific sound power level dependency

The specific sound power approach gives a good first estimation on what the sound power of the fan will be, when it operates at certain performance. The contribution of the performance of the fan as airflow rate and pressure rise is given in equation 3. The equation assumes that the sound power dependency is to the fifth power of the flow velocity. In that case the noise generated by the fan is scalable according to the equation of the specific sound power of the fan. In the case of other dependencies the equation must be adjusted for scaling purposes. The rest of the equation determines the specific sound power level of the fan, which can be affected by the fan type, the operation point and the surrounding structures of the fan.

Fan type

An example of selecting the right fan type to the solution is presented in the following. As has been pointed out earlier, different fan types have different specific sound power levels measured in good conditions and by standardized methods. In cooling applications the fan casing and the surrounding structures can be quite different from the casings used in normal fan practice. The effect of the casing can be tremendous both on the sound power of the fan and the performance of the fan.

In figure 4 the results for a few fan types running in one surrounding structure are presented. The specific sound power levels for the radial bladed fan remain fairly constant at all tested operating points, whereas the curves for the two different type of axial fans indicate more severe changes in the operation. Especially the fan with airfoil blades has a clear optimum, which must be achieved in order to make sure of silent operation. The values of the specific sound power levels coincide rather well with earlier reference of different fan types[4].

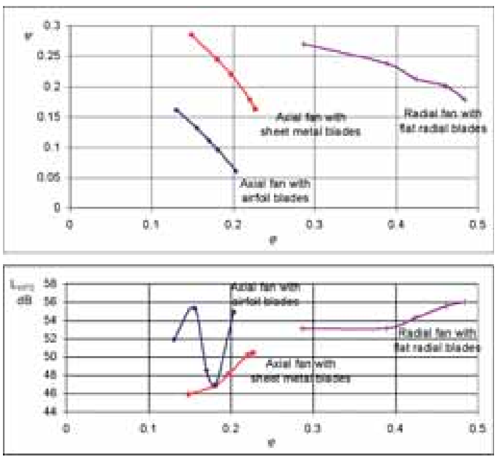

Fig. 4: Specific sound power levels for various fan types

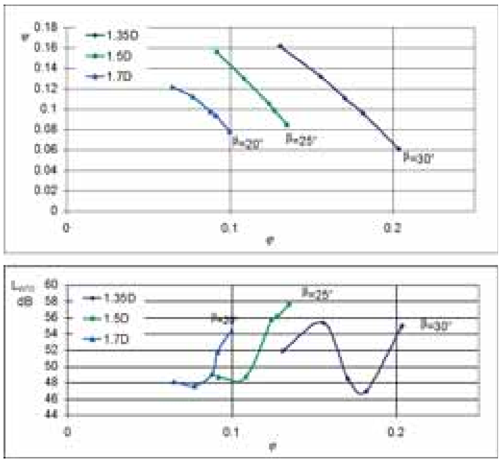

Fig. 5: The effect of the operating point[5]

Dimensioning – operation point

The basic assumption is that the fan has to be dimensioned in a way that the operation point of the fan matches the operation point of the minimum specific sound power level of the fan. This point normally also lies in the vicinity of the best efficiency point of the fan. Due to space limitations and non-optimal casing structures it is sometimes hard to estimate the pressure losses of the system, which can lead to considerable deviations from the optimum operation point. For instance different fan types and impeller diameters can alter the pressure losses in the casing or the surrounding structures of the fan, which affects the performance and operation point of the fan. This is assumed to be due to different velocity profiles behind the impeller. Normally a suitable combination of impeller diameter, blade angle and rotational speed is found to fulfil the requirements.

An example of the effects of the casing on the impeller performance and the operation point is shown in figure 5. All three fans are of the same make but the dimension and blade angle combination has been chosen in order to satisfy the airflow and pressure loss requirements of the application. The operation point of the fan that fulfils the requirements is marked as the second point from the right in figure 5. The operation points of the two larger fans deviate considerably from the optimum and therefore the sound power levels are much higher than for the smaller fan. The difference between the best and the worst solution here is from 5 to 9 dB, whereas the difference between the optima is negligible.

Surrounding structures

The structures in the vicinity of the fan can have different type of effects on the fan performance and noise generation. These structures can be for example distances between the impeller and obstructs both on the pressure or the suction side, tip clearances, type of surroundings the impeller rotates in, guide vanes and so on. The following paragraphs represent some experimental results that enlighten the effects of the surrounding structures of the fan impeller. The aim is to improve the flow conditions of the impeller so that the noise generation mechanisms are diminished to a minimum.

Tip clearance

The tip clearance of the impeller is normally determined by the ratio of the radial space between the blade tip and the shroud and the impeller diameter. The tip clearances presented in this paper vary between 0.5 to 1.5%, which were realistic for the application under investigation. Depending on the application smaller or larger tip clearances can be applied. The effect of varying the tip clearance is shown by prediction models created from experimental test results[6]. The results indicate that the effect of the tip clearance depends on the operation point of the fan. The performance curves of the fan in figure 6 show that the differences in the specific sound power levels between the small and the large tip clearances increase when the pressure rise of the fan increases. The effect of the tip clearance on the specific sound power level is almost 6 dB at higher pressure rises of the fan and it decreases down to 3.5 dB when going towards free delivery operation of the fan. The nature of the effects is broad band as can be seen from the 1/3-octave band frequency spectra in figure 7.

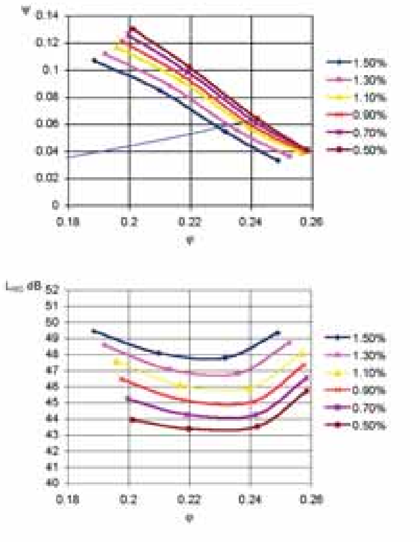

Fig. 6: The effect of tip clearance on the specific sound power curves

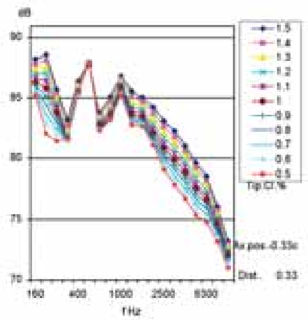

Fig. 7 : The 1/3-octave band spectra

The shape and length of the inlet shroud

In cooling applications often a fairly short inlet shroud is used in order to direct the flow in a radial direction from the trailing edge of the impeller blades. This is thought to improve the operation of the fan, which it undoubtedly does in many cases. In some cases as shown in the following results the use of a longer inlet shroud can improve the performance of the fan when the noise generated is concerned. Figure 8 presents a few inlet shroud configurations that have been tested. The results are only from one operation point of the fan and the results have been given by difference in dB compared to the best solution.

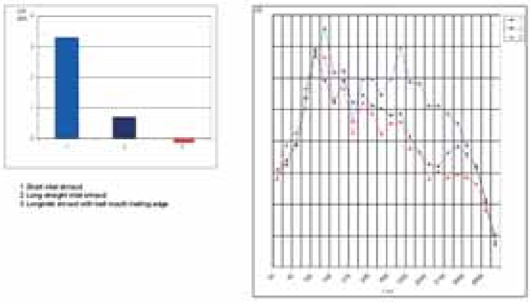

Fig. 8: The effect of the shape of the inlet shroud

It must be pointed out that there is a minimum distance between the long inlet shroud and the wall behind the impeller to get the configuration work properly. That might cause some problems in some applications, where the available space is very limited

The positioning of the impeller in the shroud

In some cases the position of the impeller is very important considering the noise generated by the fan. Figure 9 shows an example of how the sound power varies when the axial position of the fan has been changed systematically in the shroud.

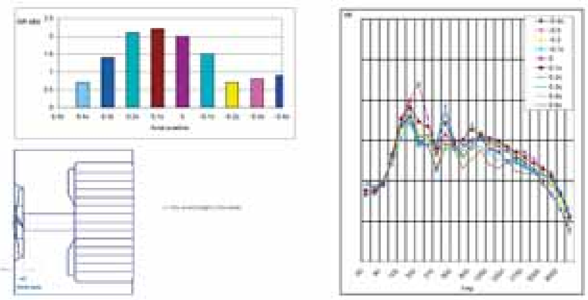

Fig. 9: The effect of the axial position of the fan in the short inlet shroud.

The best point seems to coincide quite well with earlier studies and the manufacturer's suggestions being at the position, where the impeller trailing edge is clearly over the edge of the inlet shroud. The difference between the best and the worst case is almost 2 dB.

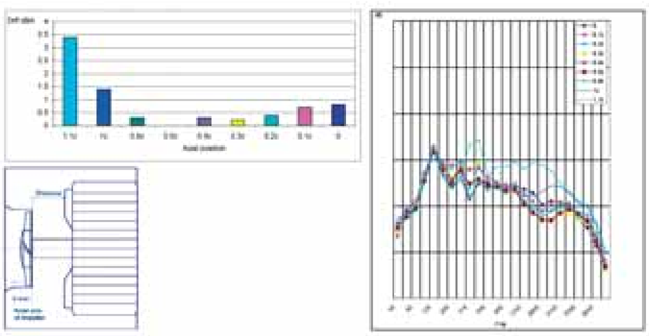

Fig. 10: The effect of the axial position of the fan in the long inlet shroud.

Using a longer shroud however shows slightly different behaviour and the situation seems to be somewhat more stable than with the shorter shroud. The sound power level of the fan starts to rise, when the impeller is brought towards the font end of the inlet shroud, which is understandable, because the impeller is way out of the shroud on the suction side, which affects the velocity profile at the blade tip.

Conlusions and further work

The use of a mock up is a useful means of investigating the effects of various design parameters of a cooling arrangement. The use of an air supply system and pressure plenum enables to verify the performance thoroughly regarding the operation point of a fan in a cooling system.

It is obvious that there are several ways of looking at fan noise and applying measures in order to design quiet cooling applications. When designing and verifying the performance and noise characteristics of the cooling arrangement it is important to realise what the possible cause of excessive noise is. A precondition in order to succeed is to get the right fan in the right application with the optimum operation point. This requires good assessment of the resistance curve of the system and also a good match of the impeller and the casing. In some cases it is necessary to take the effect of the impeller on the resistance curve of the casing or ductwork into consideration. Interaction between different impeller and casing combinations can lead to considerable differences to the sound power of the arrangement. The effect of surrounding structures can be just as important a matter to take into consideration. Bad design of structures in the immediate vicinity of the impeller can destroy the noise characteristics of an otherwise perfectly designed and dimensioned fan arrangement.

There seem to be a lot of individual and also interactive factors affecting fan noise, especially in cases where the impeller is installed in an environment it has not originally been designed for. It can sometimes be hard to detect and avoid the most influential factors in real applications. In some cases it has not really been clear when the effects have been due to single changes in the noise generation mechanisms or when the main cause has been for instance a change in the operation point of the fan. To find out more of the phenomena involved requires more research work in the field. The aim is to study the flow phenomena in the casing and ductwork and to combine the data with sound power measurements. Methods to measure the performance of the fan in non-standard operating surroundings will also have to be improved and developed.

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