HIGH TEMPERATURE TESTING AND CERTIFICATION OF FANS FOR TUNNEL VENTILATION

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ABSTRACT
In case of a fire incident the axial fans used for smoke and heat extraction in European road tunnels should be capable to handle air and smoke with temperatures of 250 ºC or 400 ºC for a period of 90 to 120 minutes. Increasingly authorities and tunnel operators require certification of such fans in accordance with European Standard EN 12101-3. The Zitron Group has tested and certified numerous axial fans at different testing institutes.
In the paper Zitron Nederland will share their views, experiences and lessons learned during the design, installation and certification of large axial fans for high temperature smoke extraction in road tunnels.

1. INTRODUCTION
One of the main functions of a ventilation system is to create sufficient time for self-rescue in case of a fire incident. Therefore it is important that smoke extraction fans are able to operate for a certain time at elevated temperatures. Contrary to fans for fresh air supply, the fan exhaust fan design has to be based on the high temperature requirements specified by the customer. The performance of the exhaust fan at high temperature operation needs to be verified. This can be done by carrying out a high temperature test in a certified test facility. Alternatively the fan maker can demonstrate suitability for high temperatures by determining the stresses in the critical parts of the fan and compare these stresses with the high temperature properties of the materials applied. The latter option is considerably less costly.

2. HIGH TEMPERATURE FAN DESIGN

Mechanical design of high temperature extract fans
In general tunnel ventilation systems require a minimum fan design life time of 40 years. To achieve this a design safety factor for combined (static and dynamic) stresses in normal operation of 2 is used by Zitron, see Figure 1.
High temperature material properties vary significantly for short operation compared to continuous operation. Emergency operation in case of a tunnel fire is usually limited to 90 to 120 minutes.
It is generally accepted that after emergency operation critical parts such as blades and drive motor may have to be replaced. Because of this and the limited emergency operating time lower safety factors can be allowed for the high temperature design.
For the high temperature design Zitron uses a safety factor for combined stress of 1.5, see table 2 below.
Correct application of material properties over time is essential for high temperature design. Especially for aluminium alloys there is a large difference between the material properties at high temperature for continuous operation and those for one and a half or two hours.
**Figure 1**: Safety factor definition

**Table 1**: Safety factors and the materials used for fan parts

<table>
<thead>
<tr>
<th>Part</th>
<th>Material</th>
<th>Safety factor</th>
<th>Safety factor</th>
<th>Safety factor based on:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal operation</td>
<td>Emergency operation</td>
<td></td>
</tr>
<tr>
<td>Blades</td>
<td>EN-GJS-400-15</td>
<td>2</td>
<td>1.5</td>
<td>Static and dynamic load</td>
</tr>
<tr>
<td></td>
<td>EN-GJS-500-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blade shaft</td>
<td>34CrNiMo6</td>
<td>2</td>
<td>1.5</td>
<td>Static and dynamic load</td>
</tr>
<tr>
<td>Hub</td>
<td>EN-GJS-400-15</td>
<td>2</td>
<td>1.5</td>
<td>Static load</td>
</tr>
<tr>
<td></td>
<td>EN-GJS-500-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WStE460</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static parts</td>
<td>S235JR</td>
<td>2</td>
<td>1.5</td>
<td>Static load</td>
</tr>
</tbody>
</table>

2.2. Cooling and thermal isolation of the inner tube(s)

To limit the temperature in the inner tube during a fire emergency, the fan can be equipped with thermal isolation and an external cooling fan, see figure 2. This combination of a cooling fan and thermal isolation reduces the temperature of the parts in the inner tube (motor, hydraulic hoses and oil supply head) during emergency operation significantly.

2.3. Electric motor and cabling.

The design of the E-motor and supply cabling is primarily the responsibility of the motor supplier. Nevertheless it is important to pay attention to the following aspects

- The bearing design for the high temperature operation (e.g. larger clearance and lubrication)
- Insulation class of the windings
- High temperature test certificate of the motor.
- Power supply cable (including the connections) suitable for the high temperature operation.
3. VERIFICATION OF HIGH TEMPERATURE OPERATION CAPABILITY

3.1. Verification by tests in circuits and furnaces in accordance with EN 12101-3.

Recently Zitron Nederland fans as given in table 2 were tested in accredited test facilities.

<table>
<thead>
<tr>
<th>Road tunnel project</th>
<th>Test facility</th>
<th>Temperature</th>
<th>Impeller diameter</th>
<th>Blade adjustment</th>
<th>Installation</th>
<th>Test Set-up</th>
<th>E-Motor Power</th>
<th>Fan drive during the test</th>
<th>Fan speed</th>
<th>External cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bosruck (A)</td>
<td>Tunnel Safety Testing</td>
<td>400 °C/135 min.</td>
<td>2512 mm</td>
<td>Hydraulic</td>
<td>Horizontal</td>
<td>Fan connected to furnace by recirculating duct system</td>
<td>450 kW</td>
<td>Frequency converter</td>
<td>1000 rpm</td>
<td>Yes</td>
</tr>
<tr>
<td>Bosruck (A)</td>
<td>Tunnel Safety Testing</td>
<td>250 °C/120 min.</td>
<td>2512 mm</td>
<td>Hydraulic</td>
<td>Horizontal</td>
<td>Fan connected to furnace by recirculating duct system</td>
<td>450 kW</td>
<td>Frequency converter</td>
<td>1000 rpm</td>
<td>No</td>
</tr>
<tr>
<td>Gernsbach (D)</td>
<td>Materialprüf-Anstalt (MPA) TU Braunschweig</td>
<td>250 °C/90 min.</td>
<td>1884 mm</td>
<td>Hydraulic</td>
<td>Vertical</td>
<td>Fan mounted inside furnace</td>
<td>710 kW</td>
<td>Frequency converter</td>
<td>1500 rpm</td>
<td>No</td>
</tr>
<tr>
<td>Meistern (D)</td>
<td>Tunnel Safety Testing</td>
<td>250 °C/90 min.</td>
<td>2113 mm</td>
<td>Hydraulic</td>
<td>Horizontal</td>
<td>Fan connected to furnace by recirculating duct system</td>
<td>400 kW</td>
<td>Frequency converter</td>
<td>1500 rpm</td>
<td>No</td>
</tr>
</tbody>
</table>

Besides the cost of and the time required for the actual test and certification procedure, the cost and lead time of an additional fan-motor-unit has to be taken into consideration. This makes verification of high temperature capability a costly and time consuming method.

3.2. Verification by design calculation

Because of the cost and time required to certify an exhaust fan according to EN 12101-3, customers and authorities often accept a design report as an alternative means of verification. In this method the stresses of the rotating fan parts are determined with the finite element method. The calculated stresses are then compared with the high temperature properties of the materials. If the calculated safety factors are equal or better than mentioned in table 2 above, the fan meets the high temperature design conditions. In the last 10 years Zitron Nederland supplied over 80 exhaust fans for road and rail tunnels in Germany, Austria, Switzerland and Benelux countries where high temperature capability was verified by comparing the calculated stresses with laboratory tests of the high temperatures properties of the materials used.
3.3. Type approval for a range of large axial exhaust fans

Annex A of standard EN 12101-3 gives a possibility to obtain type approval for a range of fans. It is not required to test each and every fan of a product range provided that a list of criteria is met. These criteria relate to number of tests, stress levels, mounting arrangement, drive motor size and speed and geometric similarity.

As far as fans for tunnel ventilation are concerned, certification of a range of jet fans considering these criteria, is very well possible and has been done by various fan suppliers. However, this is not valid for large axial exhaust fans.

Large axial exhaust fans are selected and designed to meet the required duty points and operating regimes as dictated by tunnel geometry, traffic parameters and EU/national guidelines. Fan suppliers optimize fan selection by considering various parameters such as:

- Impeller diameter, hub diameter
- Number blades, blade material, blade chord width
- Blade profile uni-directional, (partly or fully) reversible
- Blade adjustment hydraulically during operation or manually at standstill
- Nominal powers and rotating speed(s) of drive motors

The optimization is aimed at low energy consumption. This is an important factor as apart from the operational cost, exhaust fan power consumption influences installation cost of power supply systems and cabling considerably.

The result of this optimization process is that the chance that a tested and EN 12101-3 certified large exhaust fan design can be used for a future tunnel requirement is very small. Insisting on application of an already certified fan may result in sub-optimal fan design and higher installation cost. Furthermore it is our experience that certifying bodies are hesitant, if not unwilling to issue EN 12101-3 certificates for large axial fans for tunnel applications when the fan is similar but not identical to a tested fan.

This applies especially to large exhaust fans with blade adjustment during operation.

3.4. Evaluation of test certificates

Currently the version EN 12101-3:2002 is in force. The version EN 12101-3:2010 is expected to be released shortly. In case the validity of a fan test certificate has to be evaluated for use in new installations, following aspects should be considered:

- Impeller diameter, hub diameter, blade adjustment mechanism and number and geometry of blades of selected fan have to be identical to tested fan.
- Nominal motor power should not be higher and be no less than 80% of the power of the tested fan.
- Drive motors should be identical, use of an alternative drive motor makes the certificate invalid.
- When the fan is to be equipped with a variable speed drive (VSD), the tested fan should also be driven by VSD. When a fan is tested without VSD the thermal load on the drive motor is lower, making the certificate invalid for VSD drive. It is possible to get around this problem when the VSD is by-passed after start-up of the fan.
- A certificate based on a test in horizontal position is not valid for a fan in vertical position.
- The EU-MEPS directive regarding minimum efficiency of electric motors up to 375 kW will result in drive motor construction changes. A certificate of a fan tested with a lower efficiency class motor will not be valid for a fan with a high efficiency class motor.

4. EFFECT OF THE USE OF AN EXTERNAL COOLING FAN.

Large exhaust fans can be equipped with or without auxiliary cooling systems, with corresponding high temperature certificates. To reduce installation and operating cost designs may choose not to install such a cooling system.

The cooling fan provides cooling to the inner tubes with the motor and to the inner tube with the rotating oil supply device and the hydraulic hoses, see figures 2 and 3. To reduce the heat flow into the inner tube these inner tubes are equipped with thermal isolation.

![Exhaust fan with auxiliary cooling fan](image)

**Figure 2:** Exhaust fan with auxiliary cooling fan

To demonstrate the effect of auxiliary cooling Zitron Nederland performed the 400 °C test on the exhaust fan for the Bosruck tunnel with cooling air and repeated the test at 250 °C without cooling air.
Test set-up
To measure the temperatures in the inner tubes 7 thermocouples type K were installed:

1: Surface of the motor at the position of the non-driven end bearing
2: Surface of the motor
3: Surface of the motor
4: Surface of the motor at the position of the driven end bearing
5: Inner surface of the tube with the motor.
6: Surface of the rotating oil supply device.
7: Inner surface of the tube with hydraulic hoses and rotating oil supply device.
Test results

**Figure 5:** Recorded temperatures, test at 400 °C with cooling fan

**Figure 6:** Recorded temperatures, test at 250 °C without cooling fan
The test shows that use of an auxiliary cooling system results in temperatures which are just above normal operating temperatures of the drive motor, even during a test at 400 °C. Without cooling system the temperatures rise quickly to temperatures close to the test temperature.

After a fire incident the fan may have to be equipped with new blades. With the availability of adequate spare blades this can be done in a short period of time.

As the temperatures during the emergency situation are not much higher than the operating temperature, the drive motor does not have to be replaced. The unavailability of the tunnel to the traffic can be reduced significantly.

For exhaust fans with auxiliary cooling a drive motor with a lower temperature certification could be considered, offering an opportunity for cost saving. Furthermore, the use of an auxiliary cooling system reduces the risk of failure from the motor, the rotating oil supply device or hydraulic hoses considerably.

5. CONCLUSIONS

- High temperature certificates of large exhaust fans based on past testing have to be carefully evaluated on validity for new applications. Most likely a new high temperature test is required.
- Availability of certificates may drive fan selection and result in less efficient fans.
- Design reports can be considered as an alternative means of verification.
- The use of an external cooling system reduces the temperatures in the inner tubes considerably resulting in less down time of the tunnel after an incident and offering opportunities for cost savings.