THE A10-TAUERN TUNNEL VENTILATION SYSTEM FROM A CONTRACTOR’S PERSPECTIVE.
(Experiences and lessons learned)
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Zitron Nederland B.V.

ABSTRACT
In recent years, numerous existing road tunnels had to be extended with a second tube or an escape tunnel to meet with the current guidelines and safety standards.

Bringing the „extended“ tunnels up to the current expectation levels poses many additional challenges.

The experience, gained during the design, installation and testing of the comprehensive ventilation system for the Tauern Motorway Tunnel Extension is presented and suggestions are made to benefit from “lessons learned”.

1. INTRODUCTION
For tunnel extension projects like the A10 - Tauern tunnel it is important to realize that these tunnels are existing tunnels, which are extended with a second tunnel-tube.
In case of the Tauern tunnel, which originally was built in the mid 70-ties of the last century, the ventilation design already provided for the 2-tube tunnel to be built at a later stage.
As a consequence of that, the fan rooms and ventilation ducts, for the second tube, were in place.
The design of these structures was based on the guidelines and standards, applicable at the time.
After the large fire-accidents in the Mont Blanc tunnel and the Tauern tunnel in 1999, the Austrian and European Guidelines and Tunnel Safety Regulations were modified and one of the major conclusions was that safe escape routes and/or -passages should be realized for all high traffic tunnels.

Present guidelines for ventilation systems in Austria are:
RVS Guidelines:
RVS 09.02.31 Tunnel-Tunnelausrüstung-Belüftung-Grundlagen Ausgabe 1.8.2008
RVS 09.02.32 Lüftungsanlagen-Luftbedarfsberechnung Entwurf Dez. 2009
RVS 09.02.33 Tunnellüftungsanlagen-Immissionsbelastung an Portalen Ausgabe 1.5.2005
RVS 09.02.22 Tunnelausrüstung-Betrieb und Sicherheit Entwurf April 2010

Furthermore Austrian tunnel ventilations systems are to comply with:
Planungshandbuch Lüftung (PLaPB 800.542.10 Version 1.0 – Ausgabe vom 16.4.2009) der ASFiNAG.

The ventilation system for the second tube of the Tauern tunnel had to be based on these new traffic guidelines and safety instructions, however taking into account that the fan rooms and ventilation ducts were already constructed and would not be modified.

Due to the substantial lower emissions from cars and trucks, the determining factor for the design of the ventilation system was no longer the normal comfort ventilation but nowadays the ventilation system design is determined by safety considerations in case of fire incidents.
Basiclly this results in higher air volumes and correspondingly square higher pressures. The physical consequences of this change in design criteria and the experiences gained during construction are discussed in this paper.
2. PARTIES INVOLVED

In October 2008 the contract for the Engineering, Supply, Installation, Commissioning and Testing of the ventilation system of the A10 - Tauern Tunnel was awarded by the ASFINAG, Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft to Zitron Nederland B.V.

Customer: ASFINAG
Asfinag Bau Management GmbH

Ventilation design: FVT - Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik m.b.H.

Site supervision (Örtliche Bauaufsicht, ÖBA): IDS Beratende Ingenieure GmbH

Ventilation system review: ILF Beratende Ingenieure GmbH

Begleitende Kontrolle (BK): Hopferwieser Consult Ziviltechniker GmbH

3. CONTRACTUAL REVIEW OF VENTILATION SYSTEM DESIGN

The ventilation system of the Tauern tunnel is represented in Fig. 1:

As a part of the contract, the ventilation system design [1] has been reviewed [2]. According to the Austrian RVS 09.02.31 the meteorological influences (barometric pressures and wind influences) need to be considered in the calculation of system pressure differentials. For the design review, meteorological data were obtained from the Zentralanstalt für Meteorologie und Geodynamik, the Austrian meteorological institute (ZAMG).

The meteorological conditions deviated from the data from a neighbouring tunnel which were used in the system design. The main consequence was that higher pressure differentials at the portals had to be taken into consideration:
### Table 1: Meteorological influences, ZAMG

<table>
<thead>
<tr>
<th>Percentile value</th>
<th>Processing of the Pressure differences at the portals</th>
<th>Processing of the Shaft Natural Draught</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NP – SP</td>
<td>SP – NP</td>
</tr>
<tr>
<td>Pa</td>
<td>Pa</td>
<td>Pa</td>
</tr>
<tr>
<td>80- Percentile</td>
<td>148</td>
<td>85</td>
</tr>
<tr>
<td>85- Percentile</td>
<td>170</td>
<td>114</td>
</tr>
<tr>
<td>90- Percentile</td>
<td>199</td>
<td>142</td>
</tr>
<tr>
<td>95- Percentile</td>
<td>236</td>
<td>182</td>
</tr>
<tr>
<td>98- Percentile</td>
<td>282</td>
<td>219</td>
</tr>
<tr>
<td>Maximum</td>
<td>511</td>
<td>417</td>
</tr>
</tbody>
</table>

The higher portal pressure differentials caused doubt on the capability of the system to control the longitudinal velocity in the tunnel in case of a fire incident. This problem was solved by installing an additional, so-called reversible fresh air impulse damper close to the middle in both tubes.

The lesson learned in this case is that the design review needs to be carried out immediately after contract award. It is not just a formality but can result in changes of fan selection and drive motor sizing, equipment which determines the delivery time of the ventilation system.

### 4. LIMITATIONS AS A RESULT OF EXISTING FAN ROOM AND VENTILATION DUCT DIMENSIONS.

**Exhaust fan configuration:**

The limitations caused by the existing fan rooms and ducts influenced the construction of the supply and exhaust fan units. The large exhaust air volume (160 m³/s per fan) through a relatively small duct in the vicinity of the fans (2,2 x 2,2 m), results in high velocities (33 m/s), causing pressure losses which are significantly higher than newly designed tunnels, where duct velocities are limited to 15 to 20 m³/s.

The normal, aerodynamically optimised fan construction consisting of inlet bell, fan casing and diffuser requires a length of approx. 9 m. The available length of the Tauern tunnel fan room was 6 m.

Apart from the higher system pressure losses, the limited length and small ducts have also a negative effect on the fan related losses and on the in- and outlet conditions.

The inlet conditions for the exhaust fans were geometrically and aerodynamically optimised using CFD, with the assistance of ILF, Fig. 2 and 3.

The optimisation resulted in 5 to 10% lower power consumption depending on operating point and fan application.
Further power savings would only have been possible after enlargement of the ventilation ducts and fan rooms. As an example we compare the exhaust fan configuration and power consumption of the Tauern tunnel with an optimised fan room- and duct lay out, Fig. 4 and 5.

TAUERN
Length of fan room: 6000 mm.
Duct suction side.: 2.200 x 2.200 mm.
Duct pressure side.: 2.200 x 2.200 mm.

OPTIMUM
Length of fan room: 9.000 mm.
Duct suction side.: 3.000 x 3.000 mm.
Duct pressure side.: 3.000 x 3.000 mm.

The lower air velocities and the significantly higher dynamic pressure recovery by the diffuser are shown in the table 2.

Table 2: Fan power consumption related to fan related losses, Tauern vs. Optimal configuration

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume m³/s</th>
<th>Duct m²</th>
<th>m/s</th>
<th>F-dyn Pa</th>
<th>ζ [-]</th>
<th>ΔP Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet core</td>
<td>160</td>
<td>4.84</td>
<td>33.06</td>
<td>639.30</td>
<td>0.10</td>
<td>63.93</td>
</tr>
<tr>
<td>Outlet core</td>
<td>160</td>
<td>4.84</td>
<td>33.06</td>
<td>639.30</td>
<td>0.05</td>
<td>31.97</td>
</tr>
<tr>
<td>Discharge duct / Diffuser</td>
<td>160</td>
<td>3.27</td>
<td>48.89</td>
<td>1398.25</td>
<td>0.15</td>
<td>12.50</td>
</tr>
<tr>
<td>Inlet</td>
<td>160</td>
<td>3.27</td>
<td>48.89</td>
<td>1398.25</td>
<td>0.15</td>
<td>12.50</td>
</tr>
<tr>
<td>Outlet</td>
<td>160</td>
<td>3.27</td>
<td>48.89</td>
<td>1398.25</td>
<td>0.15</td>
<td>12.50</td>
</tr>
<tr>
<td>Efficiency / factor</td>
<td>160</td>
<td>3.27</td>
<td>48.89</td>
<td>1398.25</td>
<td>0.15</td>
<td>12.50</td>
</tr>
<tr>
<td>Impulse losses 2=4</td>
<td>160</td>
<td>3.71</td>
<td>43.13</td>
<td>1088.28</td>
<td>0.05</td>
<td>5.05</td>
</tr>
<tr>
<td>With insurrogue</td>
<td>160</td>
<td>4.84</td>
<td>33.06</td>
<td>639.30</td>
<td>0.05</td>
<td>69.89</td>
</tr>
<tr>
<td>Without insurrogate</td>
<td>160</td>
<td>3.71</td>
<td>43.13</td>
<td>1088.28</td>
<td>0.05</td>
<td>27.28</td>
</tr>
<tr>
<td>Fan isolation damper</td>
<td>160</td>
<td>3.71</td>
<td>43.13</td>
<td>1088.28</td>
<td>0.25</td>
<td>27.28</td>
</tr>
<tr>
<td>Total Fan pressure loss</td>
<td></td>
<td>441.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In- and outlet concrete duct losses (based on assumption of 1.5 x dynamic loss)</td>
<td></td>
<td>958.95</td>
<td></td>
<td></td>
<td></td>
<td>277.33</td>
</tr>
<tr>
<td>Total losses</td>
<td>1409.71</td>
<td>470.15</td>
<td></td>
<td></td>
<td></td>
<td>88.50</td>
</tr>
<tr>
<td>Fan Power at 85% efficiency</td>
<td></td>
<td>365.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Auxiliary equipment:

Due to location and limited size of the fan rooms, the auxiliary components such as electrical panels, auxiliary cooling- and hydraulic units cannot be situated directly next to the fans, which means that additional provisions had to be made. Additional oil leakage units were installed, lay out and installation of auxiliary cooling air ducts, hydraulic oil tubing and supply- and sensor cabling was more complicated and time consuming, Fig 6 and 7:

5. ACCEPTANCE TESTS

The main supply and exhaust fans have been full size tested to demonstrate the required air volumes, pressure rise and energy consumption. Based on the test results the expected annual energy consumption has been confirmed. The fan test results provide a solid basis for site acceptance tests in terms of leakage and overall system performance. For accurate air volume measurements, nozzles were mounted in the exhaust duct, Fig. 8.

The leakage test revealed high leakage volumes. This required renewal of the sealing and improvement of the tightness of the joints in the concrete exhaust- and supply-air ducts as well as improving the sealing flanges around the existing dampers, in the existing tunnel.

The fire test revealed that in the event of a fire incident in combination with a high natural draught in the tunnel, it may be recommendable to use 2 exhaust fans, instead of 1, for exhaust of the smoke out of the tunnel. In that particular case 1 or 2 more fire dampers should be opened.

This was recommended by the BMVIT (Bundesministerium für Innovation and Technology) and its consultant HBI.
6. CROSS PASSAGE VENTILATION

Ventilation of the cross safety passages between the tunnel tubes.

In case of a fire, the cross safety passages must be kept free of smoke. This is realised by an over-pressure of approx. 50 Pa, generated by the fan placed at the non-incident traffic tube side of the passage. To keep the possibility to manually open and close the cross passage doors with reasonable force, the over-pressure should not be in excess of 50 Pa.

When the cross passage doors are opened, the fans need to be accelerated to maintain the 50 Pa over-pressure. With an opened cross passage door the air volume must be increased to a level which results in 2.5 m/s air speed through the opened cross passage door. Upon closing of the cross passage door, the fan speed must be decelerated to reduce the pressure rise caused by closing the cross passage door.

The relatively long time required to accelerate and decelerate the fans is a disadvantage of this process, the system reacts relatively slow on opening and closing the doors. This disadvantage is also found at other cross passage ventilation systems.

To overcome this disadvantage we see following possibilities:

- Use of slide doors
  The advantage of a sliding door is that it is possible to open these with a limited force, also at higher over-pressures. In Switzerland we have seen cross passages with sliding doors. The response time of the system is still somewhat slow, but the influence of the force required to open the doors is limited.

- Use over-pressure dampers.
  The best option to keep the over-pressure in the cross passage more or less constant is the use of pressure relief dampers. The size of these dampers should be the same as the area of the doors. In this case the response time of the system on closing and opening cross passage doors is reduced significantly (example Wattkopftunnel, Germany)

Aspects like available space and economic considerations may prevent the use of sliding doors and pressure relief dampers

7. FAN STALL PREVENTION

The fresh air for the 4 supply fans is sucked from a common fresh air duct, the 4 exhaust fans blow into a common exhaust duct. This may result in fan stall during starting additional fans or increasing air volume of the fans. The fans are equipped with a stall measuring device, therefore it is possible to measure the stall line of supply and extract fans the fans at site.

To not only determine but actually prevent fan stall from occurring, electrical contractor Dürr Austria has installed an active fan stall prevention routine, which operates as shown in Fig.9:

![Fig. 9: Air volume vs. % of full blade angle](image-url)
If the operating point of the fan is below the line RG2 the blade angle is increased when a higher volume is required.
If the operating point is above the RG2 line the blade angle will not be increased when a higher volume is required.
When the volume flow is reduced (due to a higher volume of other fans) and the operating point is above the RG1 line, the blade angle is reduced by 3 degrees. After 30 seconds the system checks again if the operating point is still above the RG1 line, when that is the case the blade angle is reduced again.
When the operating point is above the stall line, the fan will be stopped (only during normal operation).

8. COMMERCIAL ASPECTS

Contracts like the Tauern tunnel ventilation system supply are subject to a price escalation formula in which the final price is determined based on the value of indexes for labour and material.
The prices in the contract are based on the submission date of the tender, which was June 30, 2008.
In the period 2005 to 2008 the material prices had increased substantially because of the economic boom and high demand from high growth rate countries like China and India.
The second half of 2008 the world economy came into a recession, due to the financial crisis in the USA which spread later to Europe. As a result the material prices went down dramatically, table 3.

Table 3: Price index for iron and steel, resulting indexes for labour and others

<table>
<thead>
<tr>
<th>Month</th>
<th>Wholesale price index</th>
<th>51.52.21 Iron and Steel</th>
<th>Others</th>
<th>Labour</th>
</tr>
</thead>
<tbody>
<tr>
<td>jun-08</td>
<td>151,52</td>
<td>21</td>
<td>127,78</td>
<td>130,02</td>
</tr>
<tr>
<td>jul-08</td>
<td>152,32</td>
<td>21</td>
<td>130,62</td>
<td>138,50</td>
</tr>
<tr>
<td>aug-08</td>
<td>153,02</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>sep-08</td>
<td>153,72</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>oct-08</td>
<td>154,42</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>nov-08</td>
<td>155,12</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>dec-08</td>
<td>155,82</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>jan-09</td>
<td>156,52</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>feb-09</td>
<td>157,22</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>mar-09</td>
<td>157,92</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>apr-09</td>
<td>158,62</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>mei-09</td>
<td>159,32</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>jun-09</td>
<td>159,32</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>jul-09</td>
<td>159,32</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>aug-09</td>
<td>159,32</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
<tr>
<td>sep-09</td>
<td>159,32</td>
<td>21</td>
<td>130,62</td>
<td>94,20</td>
</tr>
</tbody>
</table>

Example:
Price basis       | June 2008 | Due date Sept. 2009 |
Labour:           | 127,78    | 132,69             |
Others:           | 130,02    | 138,50             |
Labour:           | 174,60    | 94,20              |

source: Statistik Austria

6th International Conference ‘Tunnel Safety and Ventilation’ 2012, Graz
Calculation:

<table>
<thead>
<tr>
<th></th>
<th>Price Split-up %</th>
<th>Po without esc. %</th>
<th>Lo / Mo</th>
<th>Ldd / Mdd</th>
<th>Price factor</th>
<th>Pdd with esc. %</th>
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<tbody>
<tr>
<td>labour</td>
<td>20</td>
<td>20</td>
<td>127.78</td>
<td>132.69</td>
<td>1.04</td>
<td>20.77</td>
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<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wages</td>
<td>48</td>
<td>48</td>
<td>130.02</td>
<td>138.50</td>
<td>1.07</td>
<td>51.13</td>
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<tr>
<td>Material</td>
<td>32</td>
<td>32</td>
<td>174.60</td>
<td>94.20</td>
<td>0.54</td>
<td>17.26</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td></td>
<td><strong>89.16</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Under normal market conditions prices which are subject to a price escalation formula will slightly rise during the construction period. For the Tauern Project the final price decreased with more than 10% between tender submission date and invoice date. A main-contractor can mitigate this deficit by negotiating lower prices with sub-contractors based on lower material prices or by agreeing the same price escalation formula for sub-contracted supplies.

However, a substantial part of the risk of negative price variation will remain with the main contractor.

9. LOCAL PARTICIPATION

Local participation in facilitating and assisting with local assembly, installation, removal and re-cycling, supply of steel construction work, such as platforms, stairs, ramps, as well as ducts, railings and other construction parts have proven to be vital for a smooth site erection and installation.

Another advantage of the involvement of local contractors is that local fitters for assembly and installation work can gain experience with a tunnel ventilation system.

Especially when staff of local sub-contractors are invited to join at commissioning, testing and the instruction sessions, they become specialist service fitters for the ventilation equipment.

So in case of a failure or damage, it is possible to have an engineer in place, for the first diagnoses, within a very short notice period. The specialist local staff can also be employed for service and maintenance under supervision of a specialist from the factory, making this more cost effective than sending a full team with associated cost for travelling costs and lodging.

10. CONCLUSIONS AND RECOMMENDATIONS

Design review

It is essential that the design review takes place immediately after contract award as the Tauern project has shown that it is not a mere formality but can have significant consequences on selection an sizing of ventilation system components.

Fan room and – duct dimensions

Allowing for sufficient space for fans and ventilation components will reduce capital cost and energy consumption.

Acceptance tests

Carrying out site tests is not only required to prove system performance but can also reveal further optimisation possibilities.
Cross passage ventilation
More attention should be given to the response time for pressurizing cross passages.

Active fan stall prevention
Processing the data from air volume and fan stall measuring device enables active stall prevention which is advantageous for fan durability and ventilation system reliability.

Price escalation
Price escalation formula’s can, in unusual circumstances result in lower final equipment prices.
Main-contractors should take this into consideration during tender preparation, agree same conditions with sub-contractors. Customers may allow for limits in price variation to limit overall economic risk for longer term contracts.

REFERENCES:
[2] B. Höpperger, ILF Consulting Engineers (2008); Review calculations of the ventilation system Tauerntunnel.