PRACTICAL ASPECTS OF TUNNEL DAMPER INSTALLATIONS IN FALSE CEILINGS

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ABSTRACT

This paper focuses on some of practical aspects of selecting and installing these dampers into false ceilings with both transverse and semi-transverse ventilation systems.

Starting with the issue of damper selection, the paper discusses the temperature criteria required of the damper/actuator assembly for both operational security and structural integrity. The size and number of damper modules is determined by a variety of practical considerations, and these are reviewed both from a commercial and from an engineering perspective.

The issues of damper orientation and installation (recessed or proud within the duct) are addressed from an aerodynamic pressure drop and an installation / maintenance perspective, and new cost-effective proposals are presented. The paper also reviews the issue of aerodynamic fairings and discusses their cost / benefit relationship.

Key words: Ventilation, tunnel, fire, smoke, installation, commissioning

1 INTRODUCTION

The highly destructive recent tunnel fires in Europe have given further impetus to upgrade the road tunnel ventilation systems to enhance the safety of the travelling public. The newly designed ventilation systems can be significantly more effective in exhausting smoke from tunnel fires, primarily because of the increase in ventilation capacity and through localising the exhaust flow through large tunnel dampers.

However, there is evidence that international 'best practice' relating to tunnel damper selection and installation is not necessarily being followed in recent refurbishment and new-build projects being undertaken in Alpine countries. This paper addresses some of these issues for the purpose of enhancing the debate regarding life safety in traffic tunnels.

2 TUNNEL DAMPER SELECTION

Selection of the appropriate tunnel damper is a key instrument to enhance life safety in tunnels, achieving reliable ventilation operation and holding down both the initial and running costs of mechanical and electrical services in tunnels.

Unfortunately, only a few product standards for tunnel dampers are available to assist the tunnel designer in the selection of appropriate tunnel dampers for installation in false ceilings. In the absence of such standards, engineers in Alpine countries have tended to use prior local practice, rather best international practice, to specify tunnel dampers for the large number of refurbishment and new-build projects currently underway there. An overview of prior Alpine and international best practices is presented in Table 1.

Why do Alpine countries diverge from international best practice, and what are the consequences of these differences on their tunnel damper selections?

Specification	Alpine Prior Practice	International Best Practice
Blade Actuation	Parallel bladed, to enable an aerodynamic air-stream from traffic space to ventilation duct.	Opposed-blade or parallel bladed operation, depending on specific requirements (see below)
Pressure Loading	Typically 2 to 10 kPa, comprising the sum of maximum static (fan) pressures and dynamic event (e.g. sudden shut-off) pressures to generate no more than a specified blade deflection (e.g. 2 mm).	Maximum static (fan) pressures to produce blade deflection < blade span/250. Repetitive cycling allowed for through fatigue-life specification. One-off dynamic events allowed for through stress considerations.
High-temperature cycling	Various ad-hoc requirements, with temperatures between 250 to 400 ºC for 1 to 2 hours.	French standard 2000-63 calls for a cycling requirement of 400 ºC for 2 hours.
Fire integrity requirements	None specified.	Dampers form an integral part of the false ceiling and should therefore be covered by fire integrity specifications such as BS 476-20, or more demanding national standards such as the hydrocarbon curve for the UK.
Leakage requirements	Only cold-flow (not hot flow) leakage rates through the blades (not case) are specified.	Cold-flow leakage rates as per UL555S Class 1 [71 l/s/m^2 @ 3 kPa], hot-flow leakage rates as per BS EN 1366-2 [360 m^3/h/m^2 @ 300 Pa].

Table 1: Prior Alpine and International Best Practices relating to Tunnel Dampers

It is the authors' contention that the reason for this situation is the limited size of the tunnel damper market in Alpine countries prior to recent catastrophes including the Mont Blanc and Tauern Tunnel fires. This small market size reduced active competition, and local manufacturers developed their own standards to satisfy the small demand for tunnel dampers in Alpine countries.

After the safety reviews undertaken by tunnel safety authorities in Switzerland, Austria and Germany (amongst others), large public works programmes were initiated to replace the slot extracts in existing road tunnels with multi-bladed tunnel dampers. Such large exhaust openings, set every 50 to 100 m in the false ceiling, were shown by the Memorial Tunnel experiments in Boston, USA to be significantly more effective in limiting smoke movement than the slot extracts.

However, the Alpine safety reviews did not encompass the detailed tunnel damper specifications, which for the greater part were carried over from the earlier phase. This has the unfortunate consequence that the new dampers installed do not fully conform to international best practice, and furthermore may be somewhat more expensive because of this nonconformity. We now turn to some of these selection issues in detail.

2.1 Blade actuation

Prior Alpine practice calls for parallel-bladed dampers, presumably to enable an aerodynamic air-stream from traffic space to the ventilation duct. Opposed-blade dampers are hence strictly ruled out of most Alpine tunnel projects. However, this specification does not take the following considerations into account:

- Parallel-bladed dampers cannot achieve any fire integrity under hydrocarbon or BS 476-20 conditions, since they cannot be designed with any blade interlocking.
- The pressure drop difference across a parallel-bladed damper as opposed to an opposed-bladed damper is negligible in comparison to the total fan head (of the order of 10 Pa compared to 1 kPa). The pressure difference reduces even further when the blades of the opposed-blade damper are oriented parallel to the tunnel axis.
- Opposed-blade dampers can control the flow far better than parallel-bladed dampers, since they can generate higher pressure drop coefficients at smaller blade angles (see Figure 1). The problems of commissioning tunnel dampers to achieve uniform flow through all dampers during normal operation would therefore be significantly reduced, since the opposed-blade dampers can be set over a wide range of angles. Parallel-bladed dampers are restricted typically to the last 15º of movement in order to adequately throttle the flow.

None of the above discussion should be taken to imply that opposed-blade dampers are always superior to parallel-bladed ones, only that more care should be taken to consider all factors into account when specifying such dampers.

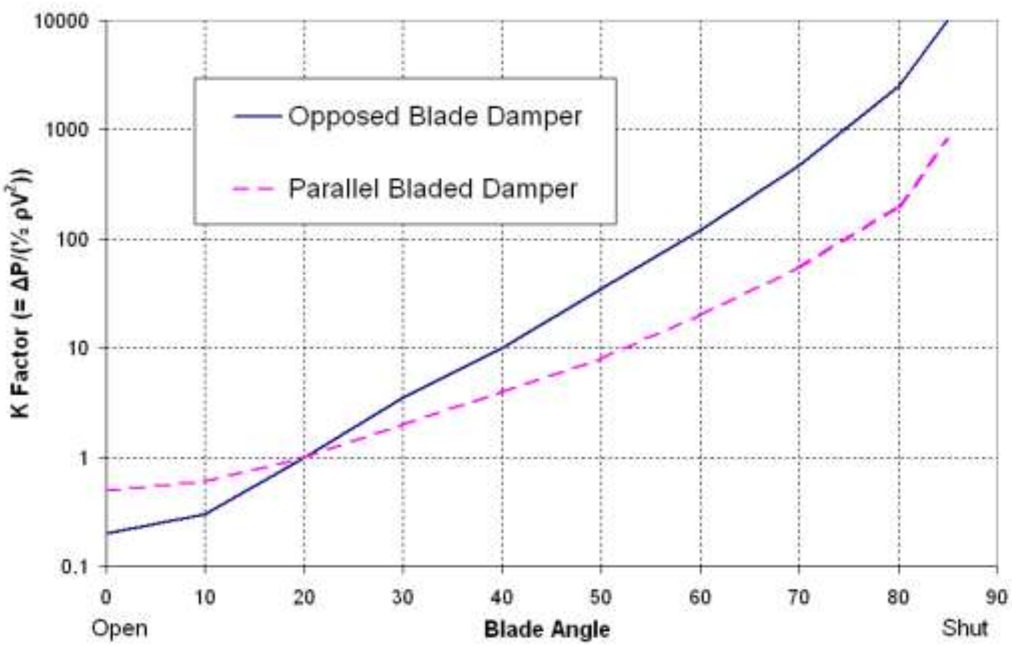

Figure 1: Measured Pressure Drop Factors for Opposed versus Parallel Bladed Dampers

2.2 Fire integrity requirements

Certification to a standard fire integrity requirement means that a damper will withstand a fire without extensive gaps appearing between the blades (hydrocarbon curve or the cellulose curve according to BS 476-20), or will leak less than 360 m^3/h per m^2 damper area at 300 Pa suction pressure (BS EN 1366-2) for a specified length of time. These are onerous constraints – during fire integrity tests to the hydrocarbon curve, temperatures rise above 1000 ºC after 5 minutes (Figure 2).

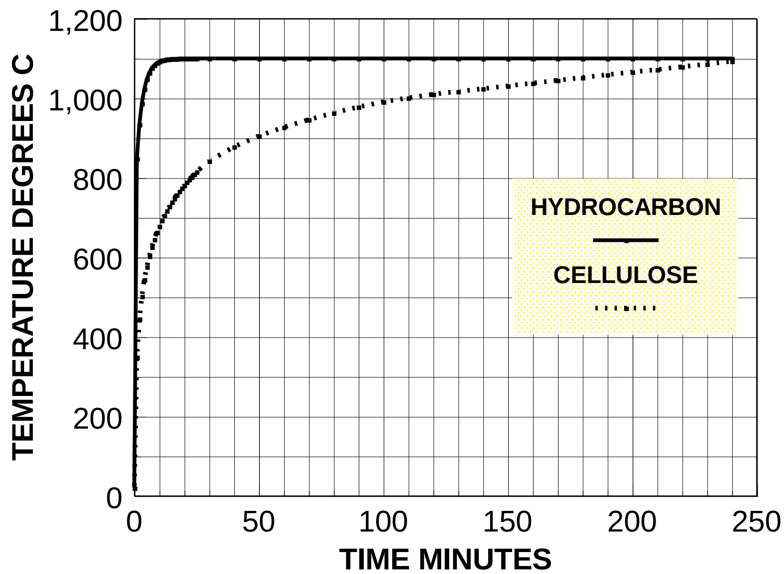

Figure 2: Time-Temperature Curves for Fire Integrity

At a time when significant amounts of engineering effort are undertaken to specify the fire integrity of the false ceilings in tunnels with transverse and semi-transverse ventilation systems, it seems odd that no such considerations have been given to tunnel dampers, which are an integral part of the tunnel structure. Would the collapse of tunnel dampers in a fire cause a collapse of the false ceiling? This issue requires further investigation.

Additionally, further fire scenarios have to be considered which may well highlight the need for damper fire integrity for smoke containment. For example, in the initial stages of a fire, hot smoke may spread bi-directionally and damage dampers either side of the fire, which effectively causes the affected dampers to behave 'open' rather than 'closed'. This prejudices against concentrating the exhaust air flow through the dampers immediately next to the fire, and hence cause smoke to spread over a wider tunnel extent, possibly endangering human lives.

For dampers located between cut-and-cover metro tunnels or in the cross-passages in bored railway tunnels, the case for dampers that are properly certified for fire integrity is very clear: passengers and rolling stock in the non-incident tunnel must be protected from the fire in the incident tunnel.

2.3 Size Considerations

Dampers are normally sized according to their emergency ventilation duty. An estimate of their cross-sectional area can be obtained from the formula below:

$$A_d = \frac{2V_c A_T}{N_d V_d} \qquad \text{Equation 1}$$

where

A_d	=	Damper gross internal cross-sectional area (m^2) = B x H
V_c	=	Critical velocity to avoid the backflow of hot smoke in the traffic space (typically about 2 to 3 m/s)
A_T	=	Cross-sectional area of tunnel traffic space
N_d	=	Number of dampers to be opened simultaneously (typically 2 to 4)
V_d	=	Maximum allowable velocity through the dampers (typically 10 to 20 m/s)

Note that the above formula does not take the production of hot smoke from the fire source into account.

Having obtained an estimate for the damper cross-sectional area, it is important to specify the breadth (B) and height (H) dimensions such that:

- The static integrity of the false ceiling is not compromised due to the concrete cut-out.
- The breadth dimension reflects the fire integrity and high-temperature cycling tests for reputable damper manufacturers, in particular with respect to the maximum allowable unsupported blade length (approx. 1.5 m for Trox JFP dampers). Failure to heed this requirement will lead to significantly increased damper cost, since additional damper modules may have to be built.
- The false ceiling can support the weight of the dampers. As a rule of thumb, Trox JFP dampers weigh about 65 kg/m^2 damper area.
- The dampers can be fed through the concrete cut-outs from the traffic space into the overhead ventilation duct. This check is normally carried out using Computer-Aided Design, using the minimum size of cut-out and the maximum size of damper within the prescribed tolerances (Figure 3).
- The dampers can be realistically loaded onto a heavy goods vehicle trailer for delivery on site. A standard trailer is 2.4 m wide, 12 m long and can stack up to 2.4 m high. Allowing for clearances between the trailer sides, palettes and the dampers, this implies a maximum damper breadth of about 2.3 m across the flanges, when the actuators are supplied separately.

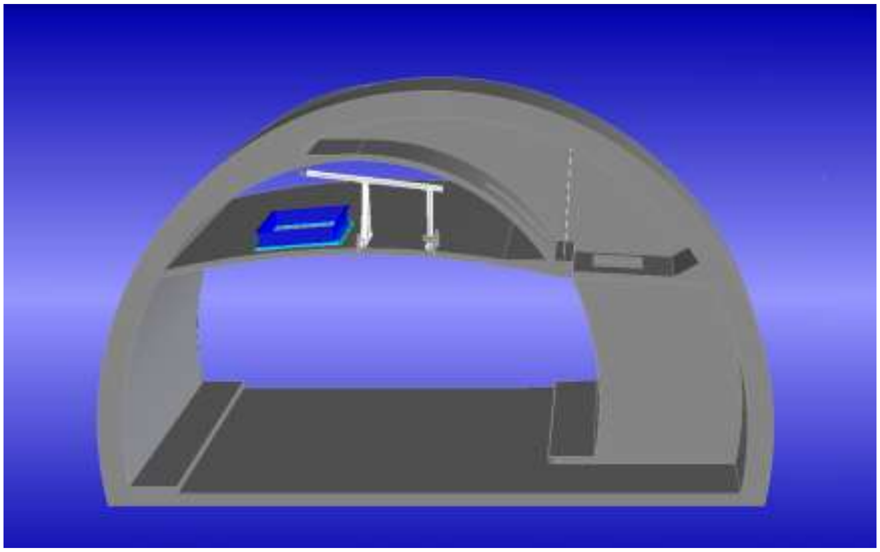

Figure 3: Three-Dimensional CAD Representation of Damper Installation

3 TUNNEL DAMPER INSTALLATION

3.1 Proud or recessed?

Currently, the accepted method of installing tunnel dampers in false ceilings is to drop them into the concrete cut-out. This recessed installation (Figure 5) has the advantage of minimising the pressure drop in the ventilation duct due to the disturbance of the flow by the dampers.

It may be beneficial to critically question the extent to which the pressure drop increases due to the presence of dampers mounted proud in the ventilation duct, and also investigating the additional benefits to be gained by such a 'proud' installation.

Assuming a distance of 100m between adjacent dampers, a damper depth of 300 mm, a damper breadth of 3 m, a duct cross-sectional area of 8.7 m^2 and a duct velocity of 10 m/s, we can show that the form drag due to the dampers will generate an additional 10 Pa of pressure drop per 100 m of tunnel length. This should be compared to a typical fan head of 1 to 2 kPa.

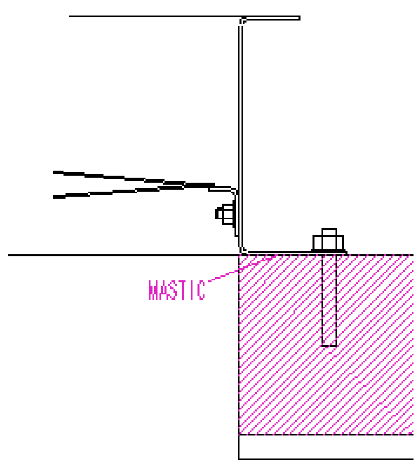

Figure 4: 'Proud' Damper Installation (on top of opening)

The *benefits* of a 'proud' damper installation include:

- Simpler maintenance and repair of the damper bearings, including lubrication and occasional replacement, without the necessity of lifting the whole damper off its mounting. This is a significant consideration during the expected 25 to 30 year life of the dampers.
- The actuator drive system is significantly simpler, meaning a cheaper installation and fewer bearing surfaces subjected to wear.
- Smaller concrete cut-outs are possible in the false ceiling for the same damper sizes, which can significantly assist in maintaining the static integrity of the false ceiling.
- If the same sizes of concrete cut-outs are chosen as for a recessed installation, lower flow velocities can be generated through larger damper sizes, which tend to offset the form drag losses calculated above.

The selection of a recessed or proud installation should therefore be undertaken only after consideration of these issues.

3.2 Methods of damper mounting

False ceilings normally have a significant degree of curvature (radii of 20 to 30 m are not uncommon), so there is no flat surface onto which to lay down the dampers. It is important however that the damper casing is held flat, or else any resulting distortion may lead to the damper blades seizing. Another important consideration is that the junctions between the damper casing and the false ceiling should be sealed, to prevent air leakage through any gaps. Such air leakage would reduce the effectiveness of smoke exhaust in a fire emergency, and complicate the commissioning of the ventilation system for normal operation.

The first dampers in refurbished false ceiling installations used a separate installation frame onto which the dampers were mounted, with a clamp arrangement to hold the damper in place (Figure 5). These installations required the use of soft concrete to provide two support plinths either side of the damper. However, most tunnel operators have now moved away from the use of soft concrete due to the risks of damaging the road surface, and installers have recognised the cost and expense of this solution.

The authors have developed a better solution that has eliminated the use of a separate mounting frame and the use of concrete plinths, whilst still maintaining the flatness of the dampers and minimising the air leakage around the damper frame. This method is simple to install and reduces the overall cost of the damper, since the mounting frame is eliminated.

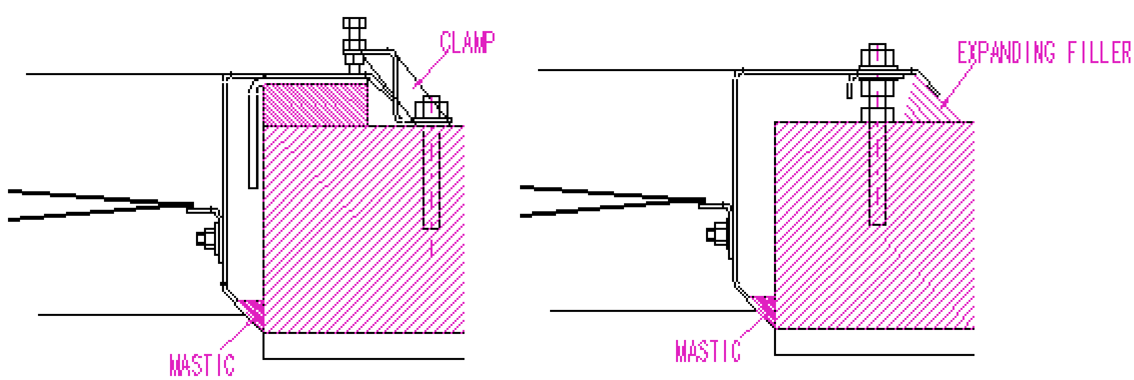

Figure 5: Recessed Damper Installation with (left) and without (right) a Concrete Plinth and Installation Frame

3.3 Aerodynamic fairings

Some tunnel dampers in Austria have been specified with aerodynamic fairings within the duct (to reduce the form drag due to the protrusion of the dampers within the duct) and also on the underside of the dampers (to reduce the contraction losses of the flow).

As in any other kind of capital investment, careful consideration must be taken to ensure that these aerodynamic fairings give value for money and can give a measurable financial return to a commercial investor.

From the calculations in section 3.1, it was seen that form drag losses due to the projection of the *full* damper height (i.e. for a 'proud' damper installation) within a duct are small. It follows that form drag losses for a *partial* damper projection (i.e. for a recessed damper installation) are proportionally smaller. The pressure drop reductions, and hence the potential fan energy savings, in providing aerodynamic fairings in recessed damper installations are smaller still.

Similar considerations can be brought forward for damper inlet fairings. Typically, one velocity head ($\frac{1}{2}\rho V^2$) is lost at discharge from a damper, and about half a velocity head is lost at entry to a damper (in the absence of any fairings). Assuming a velocity through each open damper of 10 m/s in a fire scenario, this implies that 25 Pa is lost at entry to the dampers (which are open in parallel). Even if this pressure drop figure is reduced in half by entry fairings, the projected savings are small compared to the overall fan head of typically between 1 to 2 kPa.

4 CONCLUSIONS

Through our experience in supplying and installing tunnel dampers for false ceiling applications in Alpine countries, we have identified potential improvements in the specification of these dampers to bring them up to international best practice. In particular, we have identified the importance of fire integrity as an important consideration for tunnel dampers.

Through our continuous design and innovation, we have made several suggestions to significantly reduce the cost of these damper installations and hence improve the commercial return of these projects to public and private investors. These proposals include dispensing with damper installation frames, concrete plinths and aerodynamic fairings.