Designing a Tunnel Ventilation System for Delhi Metro

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Given the dynamics of safety regulations and finance restrictions, the design of a Tunnel Ventilation System (TVS) is a complex process. First and foremost consideration must be given to applicable international safety regulations such as NFPA[1] and ITI[2]. The designers must have sound knowledge of dealing with these regulations as well as balancing the science and art of tunnel ventilation. All of this must be done within the bounds of constantly changing financial as well as technical limits.

Keeping the above view in mind we designed, supplied, tested and commissioned a TVS, the first of its kind in India, for the Delhi Metro Corridor (MC–1A) from Vishva Vidyalaya to Kashmere Gate station, involving 4km of underground tunnel.

This article will give a bird's eye view of the basic design philosophy, operation principle and major equipment selected in the first underground Metro Corridor of Delhi.

Design Principle

Tunnel ventilation systems (TVS) normally adopt either hybrid ventilation or push pull ventilation principles. The push pull alternative consists in having shafts - only at tunnel ends (no intermediate shaft). The fan at one end of the inter station operates in extraction mode while the fan at the other end of the tunnel operates in a supply mode so that air flow from the supply end to the exhaust end is induced. To achieve the temperature requirement in push pull alternative, the fans at each end of the tunnel are rated at a flow rate twice that of the hybrid alternative. Normally this alternative is used and is suitable for tunnel lengths not exceeding 1km.

If the length does exceed 1km, an intermediate shaft is introduced between stations with ventilation fans which ensure ventilation takes place between the station and the shaft as against between station ends in push pull. This is referred to as a hybrid system.

Since at MC-1A Metro Corridor, station to station distance was restricted to less than 1km, the simple push pull alternative was adopted for efficient and economic operation.

Design Documentation

A TVS needs to comply with local and international standards wherever available. Usually the main requirements of such standards are incorporated in the project design criteria manual. In our case they were incorporated in ODC (Outline Design Criteria).

The other regulations we had to follow were :

- NFPA[1] - 130
- ASHRAE Handbook
- Subway Environmental Design Handbook Volume-II
- CIBSE[3] Guide
- Outline Design Criteria

1. *NFPA - National Fire Protection Association, USA.*
2. *ITI - International Tunnel Institute, France (tunnel safety guidelines).*
3. *CIBSE - Chartered Institution of Building Services Engineers , UK.*

About the Author

R. K. Sahu is a mechanical engineer from G.B.U. & T. Pantnagar. He has over 11 years experience with ETA in Dubai & Delhi and with Blue Star Ltd. in Kanpur. He has executed DMRC MC-1A project in the capacity of manager-mechanical.

Critical Velocity

Different schools of thought exist among consultants on interpreting certain main design parameters. But the most common criterion being adopted is "critical velocity". Normally there are two interpretations while carrying out such calculations:

- Use of entire tunnel cross section
- Use of annular area around train.

However we have found that both methods are suitable for smoke extraction but the values are different in each method.

HRR: Heat Release Rate

Another important criterion in selecting the TVS is use of heat release rate in computer simulation. In our design model, we have used 20 MW as HRR in computer simulation which is quite a safe figure in comparison to the type of material used in the train.

Ambient Conditions

The ambient condition plays a major role in selecting a combined ventilation and tunnel cooling system by dumping cool air in the tunnel. Sometimes this proves uneconomical, particularly where the ambient conditions are like Delhi, resulting in an increase of cooling load, particularly in the "congested mode", in order to keep the air conditioners of the train functioning normally.

System Design

As a TVS designer our experience suggests building a tunnel of certain size or dimension and to use it for double directional traffic, considering the ventilation of tunnel in mind. However, with space constraints also in mind and to maintain the proper critical velocity in each tunnel, we provided nozzles at an appropriate location in the tunnel and the cross passage of two parallel tunnels for pressurization to prevent smoke entry through the cross passage in the event of fire.

As per the recommendation of NFPA 130, we selected all our tunnel ventilation equipment to be fire rated for 2 hours.

Selection of the best location of the fan shaft is the next important consideration. Keeping the best safety norms as well as cost consideration in mind, we chose to locate the fan shaft at the end of the station, to provide venting and when freeway exhaust system is operating to become the source of make up air.

There are many other points which need to be addressed while designing this complex TVS system.

Operation Principle

Design assumption at station public area

DBT 26°C

RH Around 55% RH

Tunnel: Not to exceed 43°C

Operational assumption

- One fire incident at any one time with only one train on fire.
- Only one train is allowed in each ventilation zone at a given time.
- Train will not enter tunnel if smoke is detected in the tunnel.
- No two trains side by side during a fire event.
- Ventilation air movement direction is opposite to the direction of egress path.
- Only one line will be congested at any one time.
- Worst case of congestion will be one train at station ahead, one train between stations and one train at station behind, while the other line will be running normally.

Operational scenarios

Using a combination of various tunnel ventilation equipments, the following operational scenarios are achieved:

- ***Normal.*** For normal movement of trains. Ventilation is effected from the piston effect of trains through specially designed independent civil structures and shafts.
- ***Congested.*** For congested movement of trains such as breakdown of a train in a tunnel, heavy train traffic etc. ventilation is effected using TV fans and booster fans / nozzles to remove heat rejected from the train air conditioners for their proper functioning.
- ***Emergency.*** For emergency situation in tunnels such as fire etc., the ventilation is effected using TV fans and booster fans / nozzles for removal of smoke to allow the safe evacuation of passengers.

The schematic diagram and matrix on the following page depicts a typical operation principle of a tunnel ventilation system in an underground metro station.

Control system

TVS has a diversified installation base and parallel action is required on various equipments simultaneously to achieve the evacuation time of 6 minutes, which is not possible without a suitable control system. Hence, a well designed control system is the backbone of a TVS.

In association with our international advisors and close interaction with DMRC (Delhi Metro Rail Corporation) we designed the control system at MC-1A to meet the stringent requirements of full operation of the emergency mode within 120 seconds as per NFPA. The system has been successfully tested.

Like all mechanical and electrical systems, all control cables are "fire survival" and devices in a hot air stream are "fire rated" to the desired extent.

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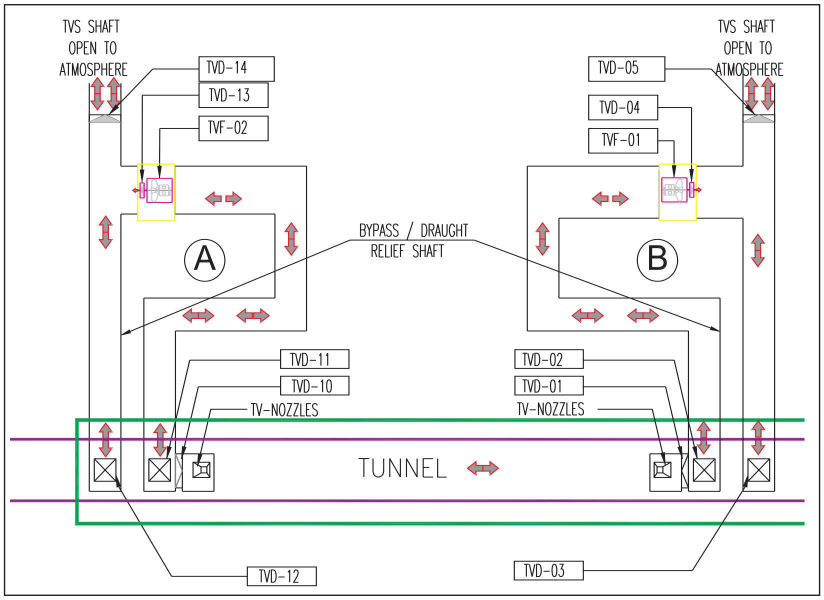


Schematic diagram showing typical operation principle of a tunnel ventilation system.

AIRFLOW - A - B												
SCENARIO	**TVF**		**TVD**									
	1	**2**	**1**	**2**	**3**	**4**	**5**	**10**	**11**	**12**	**13**	**14**
Normal	Stop	Stop	C	C	O	C	O	C	C	O	C	O
Cong./Emergency	Supply	Extract	C	O	C	O	O	O	C	C	O	O

TVF - Tunnel Vent. Fan. TVD - Tunnel Vent. Damper.

To control the complex operation of TV system, a PLC with a hot standby has been installed at all stations.

The control system at each station is interfaced with a common SCADA system and hence TV equipments at all stations are controlled simultaneously from OCC (Operation Control Centre).

Considering the criticality of operation of the TV system, the operational command to a TV system can be issued in the following order of priority:

1) OCC (Operation Control Centre)
2) SCR (Station Control Room)
3) VCP (Ventilation Control Panel)
4) LCP (Local Control Panel)

Each level acts as a fall back arrangement to the preceding command station.

Major Components

The proper selection of equipment and accessories is very important for the effective operation of a TV system.

Apart from performance requirements, the following points are also very important criteria for selection of equipment:

- Service life. The DMRC project was designed and provided with equipment having a 40 year service life.
- Fire rating.
- Reversibility of TV fans.
- Bearing life.
- Performance at elevated temperatures.
- Capable of withstanding very high pressure fluctuations.
- Reliability of operation.
- Noise level.
- Capability of TV fans reaching full speed and sudden reversal to full speed in reverse direction as per timeframe recommended by NFPA.
- Capability of dampers to reach the emergency position within recommended timeframe.
- Capable of parallel operation.
- Serviceability and maintainability.

There are very few vendors across the globe who specialize in such equipment and we had to supply equipment from all over the world to meet the stringent critera and requirement of the TV system.

Specific factory acceptance tests of equipment in USA, Germany, Dubai were conducted prior to dispatch. Fire rating tests of ducts were conducted at CBRI, Roorkee.

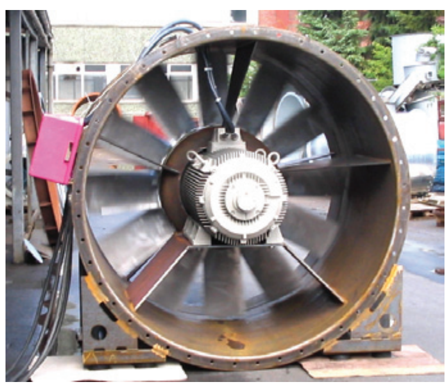
The major equipment in a TV system comprise:

• Tunnel ventilation fan. 100% reversible fans to provide necessary ventilation in tunnel. Capacity and size is very big and depends on the size of tunnel. Typical example: airflow-75m^3/sec, total pressure 1400Pa, dia. 2000mm

• Tunnel ventilation damper. Dampers for providing the proper route for air/smoke during ventilation and to achieve the desired result of supply/extract by a proper combination. Typical size: 3500mm × 3500mm

• Tunnel booster fans. Fans installed at regular intervals inside long tunnels to boost the flow of air/smoke during the ventilation process.

• Nozzles. Installed in short tunnels at discharge of fans to guide air to the tunnel and for booster



A tunnel ventilation fan under test at a factory in Germany.

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purpose.

- Sound attenuators. Installed at suction and discharge of ventilation and booster fans to reduce air borne noise.
- Fire rated duct
- Switchgears.
- Fire survival power and control cables.
- PLCs.
- Control sensors.

Conclusion

The design, installation, testing and commissioning of a tunnel ventilation system is a complex process requiring thoughtful consideration of both technical advantages and limitation of various alternatives as well as cost implication.

There are no simple rules of thumb for carrying out TVS work and it is a very vital safety system in underground stations which will help to save the life of thousands of commuters during an emergency.

It requires very specialized people and experience to design, select, install and commission such systems and to make them perform successfully. ❖