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REVIEW OF PROBLEMS OF NOISE CONTROL IN RAPID TRANSIT VEHICLE DESIGN

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INTRODUCTION

The problem of noise in underground rapid transit vehicles is more complex than in main line rolling stock design. The reasons are that rapid transit vehicles may run in tunnels, often on concrete slab track, have propulsion systems mounted on the cars themselves, have anything up to ten sets of sliding doors per car and usually have reflective interiors with a minimum of soft furnishing. Because of the short distance between stations and the need for almost continuous acceleration or braking there is always a major weight penalty in the running costs of systems. One of the few advantages that rapid transit trains have over main line trains is that they operate at much lower speeds.

Interior noise levels are determined by the level of noise in the cavities between the cars and the tunnel walls, by the acoustical properties of the body and by the vibration isolation properties of the suspension system.

EXTERNAL NOISE

External noise is usually predominated during travel by rail/wheel interaction with contributions from underframe mounted equipment and electric traction motors. The problems of achieving quiet motor alternators, air compressors and auxiliary equipment are more administrative than technical, requiring close control of sub-contractors and their specifications. The noise from the traction motors is strongly influenced by the bogie design - for instance the right-angle drive, axle hung motor using a hypoid bevel gearbox, common in European light rail systems, is inherently quieter than the frame-hung motor with gear wheel and pinion system used, for instance, by London Transport. Noise control is, however, only one of many contributions in determining the choice of bogie.

Suspension design is of considerable importance. Most bogies have primary and secondary suspensions, one isolating the axles from the bogie, the other isolating the bogie from the vehicle body. The trend is towards rubber chevron primary suspension and air-bag secondary, although some all-rubber systems are quieter than air systems - the reason being that the most significant paths of noise transmission are the stabilising links which are necessary to transmit traction and braking forces in air suspension systems.

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RAIL WHEEL NOISE

Except in systems using pneumatic types which although eliminating rail - wheel noise give penalties in non-acoustic areas such as running costs, the noise of steel tyred steel wheels running on steel rails dominates the running noise of otherwise quiet vehicles. A rigorous explanation of the mechanism of wheel-rail noise has not been made, but clearly at least two processes are involved: fluctuating forces in both wheel and rail due to imperfection in the surfaces of both excite natural frequencies in rail and wheel, and the continuous pumping of air which is expelled from the space between the tyre and the rail-head ahead of the wheel and sucked into the corresponding region in the wake of the wheel. At the speeds at which rapid transit vehicles operate the former mechanism is likely to predominate.

Scope for influencing rail wheel noise exists both at the design stage and in the course of maintenance. First of all it has been found that the noise from disc-braked stock is substantially less than that from tread-braked stock. Clearly the application of brake blocks to the tread interferes with the surface characteristics of the tread which does not occur in disc braking.

At least three designs of wheel have been developed in which the rim of the wheel is resiliently mounted. The noise benefits are small, particularly on straight and lightly curved track. Resilient track of one kind or another is a common feature, and is of the greatest importance in the case of concrete slab track, where the concrete slab is capable of radiation of noise transmitted from the rails, quite apart from the implications on sound absorption.

Special problems of rail wheel noise occur where short-radius curves are a feature of the system, since railway axles incorporate no equivalent to the automotive differential, and in order for the bogie to traverse a curve where one rail has a total length greater than the other, one or both wheels must slip in total the equivalent of the difference in rail length. The slip tends to occur in discrete steps, causing a characteristic screeching noise. At least two solutions are available - one is rail/wheel lubrication, one example of which is in use in the Frankfurt tramway system and involves the lubrication of the side of the rail head with oil expelled through a row of orifices, activated by a trip device a short distance up the track which senses the approach of a train. Another solution is to minimise the effect of rail slip, which can often excite prominent natural frequencies in the wheel itself, by fitting a vibration damping device to the wheel.

Contrary to popular belief, the flange on a railway wheel is not the sole means of steering the wheelset through curves and judicious selection of wheel tread profile and primary suspension stiffnesses can achieve flangeless steering on all but the sharpest curves and thus avoid the noise of flange against rail. The next generation of bogie designs is likely to take full account of this.

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Track conditions can have a profound effect on rail-wheel noise. The differences between the noise of the same vehicle running on smooth, polished rails and on badly corrugated rails can be as much as 20dB. Corrugation is a periodic variation in the extent of wear on the rail head. Its causes are not well understood, but clearly a factor such as resonance in either bogie suspension or in the rail or track is the most plausible cause. The wavelength of corrugation may be no more than a few millimeters. Unless its cause can be found and eliminated, the only known cure for noise from corrugation is rail grinding. Grinding can also reduce noise from non-corrugated track, and is a practice carried out regularly on several continental systems.

THE INFLUENCE OF TUNNEL ACOUSTICS

In underground systems, the acoustic properties of the tunnel are obviously of considerable importance. Firstly, the sound pressure level in the cavity between the train and the tunnel is a function of the volume of the cavity, and for this reason tube tunnels are at a basic disadvantage over rectangular cut-and cover tunnels. Secondly, the sound pressure level is influenced by the acoustic properties of the tunnel. Here the influence of ballast is most important. Ballasted track is inherently resilient, the pressure beneath the sleepers during the passage of a train varies from sleeper to sleeper due to variations in the degree of compaction of the ballast, and thus the stiffness of the rails plays an important part in creating a vibration isolation system so that rail noise is largely confined to the rails and sleepers and not fed into a large monolithic slab in solid contact with the tunnel liners. Furthermore the sound absorption of ballast is enough to be significant.

The cost of artificial introduction of sound absorption in tunnel designs can be prohibitive unless considered at the very first stage of design (so that, for instance, resonant cavities can be incorporated in moulds) and because slab track is so much cheaper to maintain than traditional ballasted track, this introduces further cost implications into tunnel noise control.

CAR BODY DESIGN

Tunnel cavity noise levels would be of academic interest only if the transmission loss of the car body were high enough to ensure acceptable internal noise levels.

The biggest problem is not the basic floor, bodyside or roof specification, but the weaknesses caused by the need for automatic sliding doors and walk-through articulations. It is rarely possible to achieve such good door and articulation seals that it is worth designing for a sound reduction index of more than 30dB or so, in the body structure. The floor design is important because of the proximity of the underframe equipment below it. Here a conflict of interest arises because the designer requires maximum stiffness of the floor panels, while high stiffness brings the resonant frequencies of panels up into the frequency range at which the requirement for sound insulation is greatest. On the other hand, the floor panels are normally of greater mass than the rest of the body panels.

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The bodyside will normally be lightweight construction, ie. aluminium or thin stainless steel sheet, and as well as providing vibration damping treatment for the metal panels, it is necessary to place considerable reliance on the transmission loss of a porous blanket in the intervening cavity. Porous materials such as mineral wool slabs and blankets have transmission loss values, which though normally ignored in the context of building acoustics are significant in lightweight multi-skin structures, at least at the frequencies of interest. There is no practical need for acoustical reasons for glazing to be more than single skin, since it is not possible to achieve great enough separation to benefit significantly from double skin, and the transmission loss of a single pane of 6 mm glass is equal to that of the rest of the car body.

It is, as already said, the door design and similar areas where there are openings in the car construction that most design effort is needed. Plug doors, which slide over the outside of the body and are then pulled inwards flush with the bodyside to close the opening, are best adapted for good sealing, but they have practical drawbacks. Other designs of sliding door must run back into pockets in the bodyside, and it is important that the pockets should not present means of ingress of noise through casual openings. It is possible only to achieve a partial seal at the sides, top and bottom when the door is closed, and in a car with eight to ten pairs of doors, the efficiency of these seals totally dominates all other aspects of noise control design. Similarly, in walk-through articulations, the problem of achieving high transmission loss and maintaining flexibility is considerable.

INTERIOR ABSORPTION

The classical model of direct and reverberant sound fields is not relevant to rail vehicles, and the influence of sound absorption by seating or acoustic linings can only be determined by empirical means. The effect is not as great as might be expected and is largely academic since a higher degree of absorption is provided in well occupied cars by passengers' clothing.

INTERNAL NOISE SOURCES

Further noise sources may exist in air conditioning or forced ventilation equipment, particularly where the former is a fully roof mounted unit. Careful attention to acoustic principles can minimise these to the point where rail wheel noise still predominates.