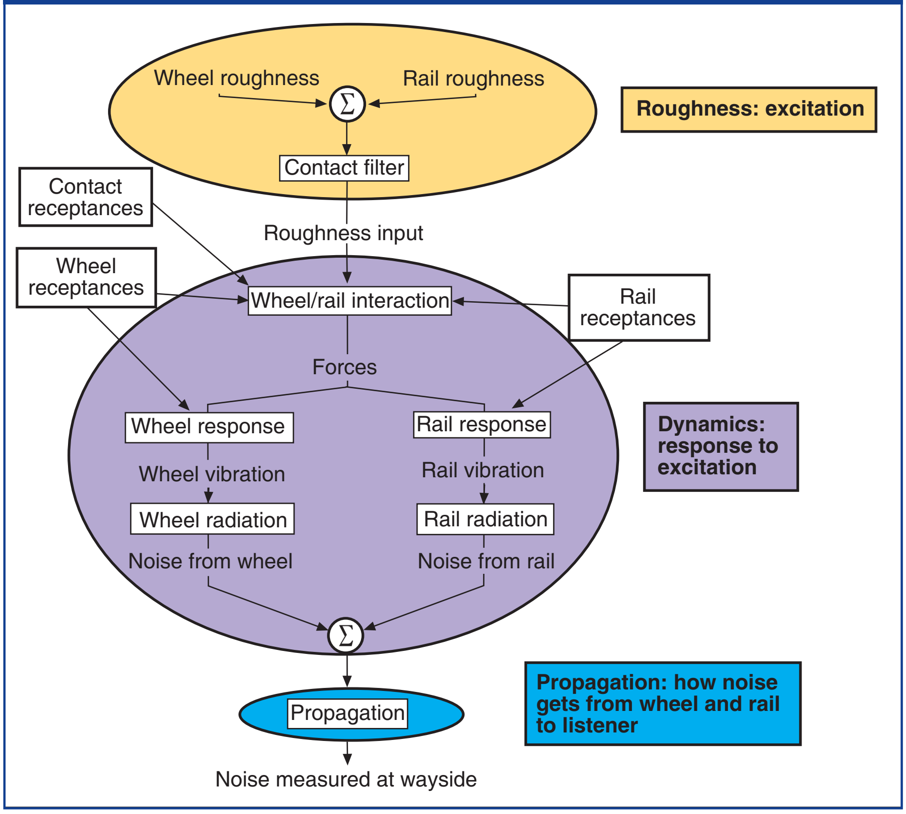
Controlling irregularities in rail to reduce noise

As transit systems proliferate and high-speed railways expand, noise will not only become more important but may in some cases even inhibit their growth. It is therefore desirable for the railway engineer to have at least a passing familiarity with the factors that influence noise and how they can be controlled, says **Dr Stuart Grassie***.

Figure 1: a model for wheel/rail rolling noise



UNTIL the mid-1980s much work on wheel/rail noise was undertaken in the United States, but since then Europe has been prominent in developing both understanding and standards. Efforts in the next decade will probably be more evenly shared between China, the US in the wake of a passenger rail resurgence, Europe, and Japan. Britain, as ever, might maintain research whose excellence far surpasses that of its railway.

In the 1970s, Mr Paul Remington and his colleagues from Bolt, Beranek and Newman proposed that wheel/rail noise comprised essentially three elements: rolling noise, impact noise and squeal. The first two depend on wheel and rail irregularities, and are therefore related to one another. Impact noise results from discrete irregularities, such as joints, whereas rolling noise derives from "broad-band" irregularities, commonly known as acoustic roughness. Squeal is caused by a stick-slip oscillation excited by large angles of attack of the wheelset and wheel/rail friction that decreases with sliding speed: this is similar to the mechanism that causes a crystal glass to ring by dragging one's finger around the rim.

This article is concerned only with noise resulting from wheel and rail irregularities, and in particular acoustic roughness. A model for this mechanism of wheel/rail noise (which is treated in greater detail in the text, *Railway Noise and Vibration* by Prof D J Thompson) comprises essentially three elements (Figure 1):

- excitation, which is the combined roughness of rails and wheels
- the mechanism by which irregularities excite vibration of the components (wheels, rails, sleepers) that radiate noise, and
- propagation of noise from these components to the observer.

A change in any one of these three elements can reduce noise. For example, reprofiling wheels and rails reduces excitation, provided it is done to a satisfactory standard. Damping treatments can be applied to wheels or rails to cut vibration. The propagation path can be influenced by noise barriers or natural features such as trees, bushes, grass and snow.

The effect of rail irregularities on noise is shown roughly in Figure 2: noise increases by 5-10dBA for a 0.050mm-depth corrugation. The *increase* is greater for disc-braked than tread-braked rolling stock as wheel roughness is lower with disc brakes, so an increase in irregularities on the rail results in a greater relative increase in the combined wheel and rail roughness.

Irregularities clearly have a significant influence on wheel/rail noise, and their control is a vital and relatively simple component of wheel and rail maintenance that has many other benefits, such as the maintenance of an appropriate transverse profile.

Because irregularities are critically important to noise, equipment has been developed to measure and thereby control them. One of the earliest examples is a trolley profilometer made

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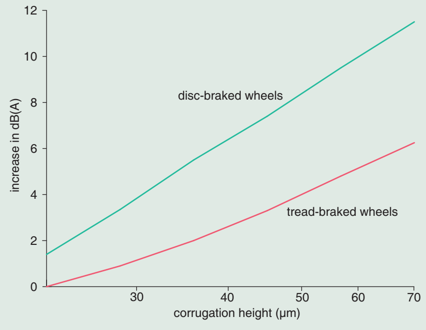
Figure 2



Effect of rail irregularities on wheel/rail rolling noise.

CAT is used to measure rail corrugation and acoustic roughness.

at Cambridge University in the 1970s. Since the 1990s the instrument of choice has been a straight-edge profilometer, which can be extremely accurate, but is usually heavy, slow to use, and limited fundamentally by the length of the straight edge that is used as a datum. Typically two operators are required and a van is needed to transport the equipment.

The corrugation analysis trolley (CAT) has been developed from the Cambridge trolley to measure at first corrugation, primarily for quality assurance (QA) of rail grinding, and later acoustic roughness. While an accuracy of microns is satisfactory for QA of rail grinding, fractions of a micron are significant for acoustic roughness. CAT, which can be carried to the site and operated by one person, measures the rail at 1m/s for corrugation, 0.5m/s for acoustic roughness. The length of track that can be measured is essentially unlimited.

Results are available for review immediately, which is useful if something of interest is noted. I used CAT to discover and then check broken rails and spalling of occasional rails on different metros, which would have been difficult if not impossible to observe with other equipment.

It has been demonstrated that CAT can give substantially identical measurements of rail roughness to traditional straight-edge instruments . Figure 3 is an example taken from a "road test" of the measuring protocol that is now contained in EN 15610:2009, which shows the so-called one-third octave spectrum of rail roughness on a test site, measured by several instruments and measuring teams. The one-third octave spectrum is a graph of amplitude of irregularity as a function of wavelength, often shown with wavelength decreasing along the x-axis. The amplitude of irregularity is the root-mean-square (RMS) amplitude in a wavelength band in which the longer wavelength is $2\frac{1}{3}$ times the shorter wavelength. The logarithm of RMS amplitude is graphed ie:

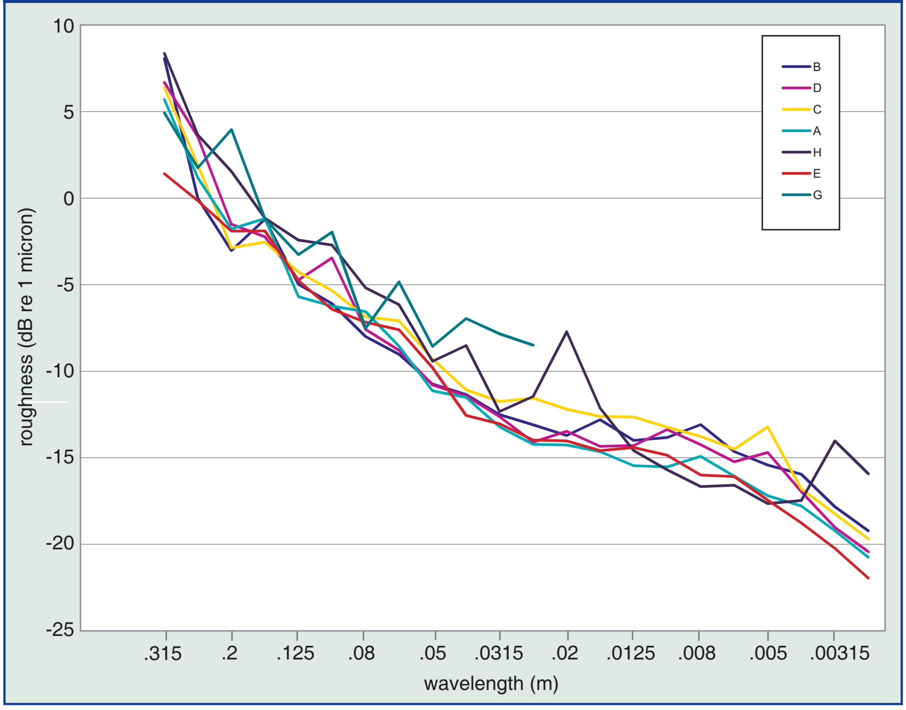
$$R = 20\log_{10}\left(\frac{r}{r_0}\right), \text{ where } r_0 = 1 \text{ micron } (0.001\text{mm})$$

In Figure 3, CAT is instrument H. The straight line is the limit spectrum for the acoustic technical specification for interoperability (TSI), which is similar to that in EN ISO 2095:2005. This is essentially rail on which irregularities are sufficiently small that acoustic type testing of vehicles can be undertaken without the effect of the vehicle being obscured by wheel/rail noise.

Many CATs are in use worldwide and it is interesting to compare roughness from different types of railway (Figure 4). On metros - the example shown is for track just before grinding - it is common for corrugation to develop in very distinct wavelength ranges: this is a consequence of the uniformity of rolling stock and speeds.

Rolling stock and speeds are also uniform on light rail systems, and likewise give rise to corrugation at

Figure 3



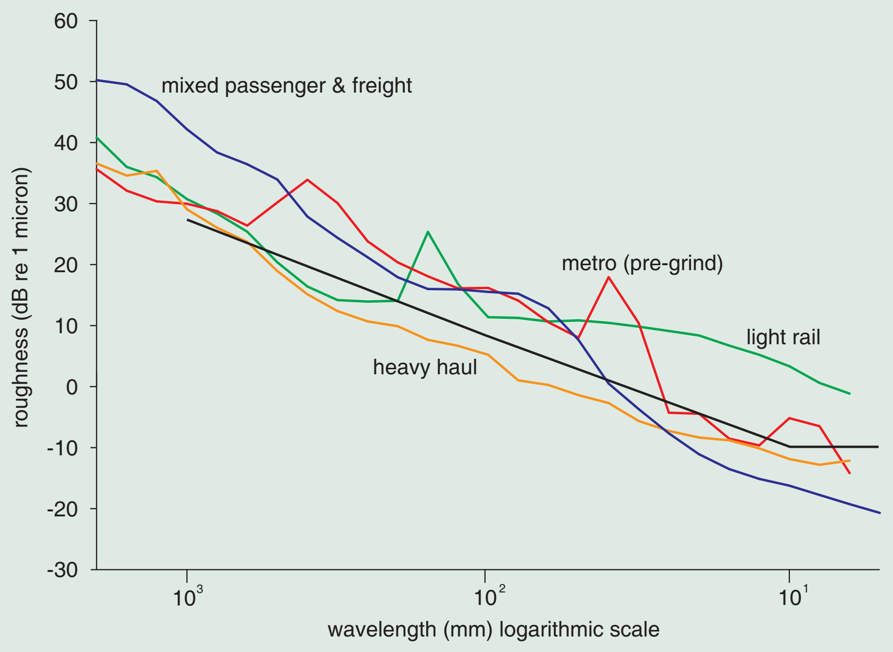
Results of the EN ISO 3095:2005 "road test": a comparison of results from several instruments and measuring teams. H represents CAT.

well-defined wavelengths. Light rail systems differ from the other types of railway insofar as short wavelength roughness (<30mm) is high and does not reduce with traffic. This results from routinely dumping sand on the track to ensure sufficient adhesion to achieve high traction and braking rates.

On mixed passenger and freight railways, where speed and traffic vary, corrugation is spread over a broader wavelength range, even if it is apparent to the naked eye and occurs as a result of the same "wavelength-fixing mechanism" that causes corrugation on metros.

Surprisingly, a well-maintained heavy-haul railway can have lower levels of roughness than the smoothest passenger line, probably because the high axleloads flatten short wavelength irregularities, and so-called pinned-pinned resonance corrugation develops slowly if at all because of the low running speeds. Perhaps suppliers should undertake acoustic-type testing of their vehicles on well-maintained heavy-haul lines!

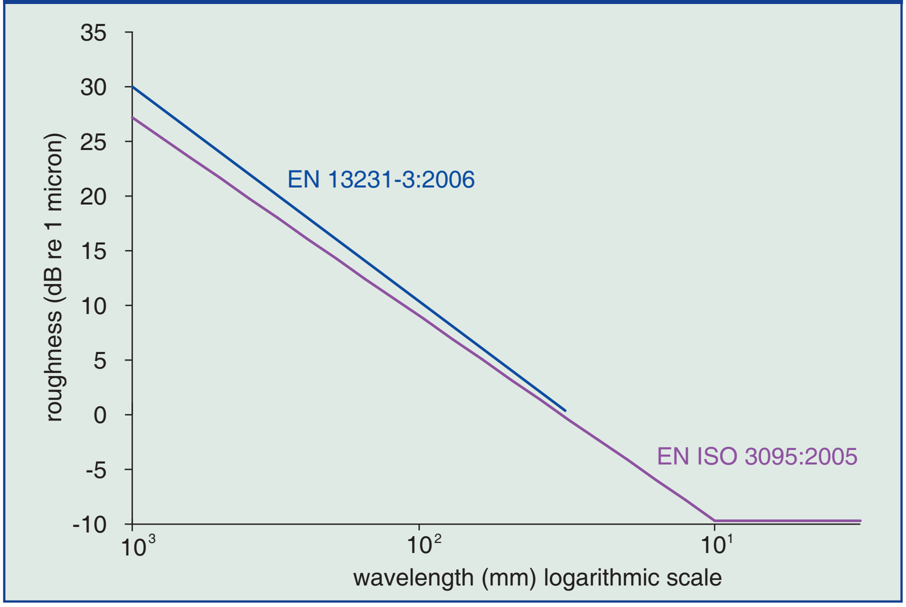
Figure 4: roughness measured on different railways



Whereas the EN ISO 3095 reference specifies limits on rail irregularities to ensure that wheel/rail noise is low, it does not say how such irregularities can be achieved. This gap is filled by the European standard on reprofiling (EN 13231-3:2006), the current version of which states three methods to decide whether residual longitudinal irregularities are acceptable. It is shown here that the method stated in terms of RMS amplitudes of irregularity is comparable with the limit spectrum stated in EN ISO 3095:2005. During the drafting of this standard in the 1990s, measurements of grinding by Loram and Speno were undertaken using CAT to show that the stated levels of residual irregularities were achievable.

The allowable irregularities increase with increasing wavelength, but the wavelength bands are considerably broader: 10-30mm, 30-100mm, etc. Each of these comprises essentially five one-third octave bands, since by a quirk of mathematics, $2^{1/3} = 10^{1/10} = 1.26$ (to three significant figures). If it is assumed that the logarithm of RMS amplitude of irregularity in these one-third octave bands varies linearly with the logarithm of wavelength, and that the combined limit for the five one-third octave bands is the same as in EN 13231-3:2006, the limit curve shown in Figure 5 is obtained for wavelengths of more than 30mm. This is almost identical to the limit line required by the standards that have been derived from considerations of noise, ie prEN 15610 and EN ISO 3095. For shorter wavelengths, typical reprofiling operations cannot achieve the low levels of irregularity required by the acoustic standards, but traffic usually reduces roughness at these wavelengths (Figure 4).

Figure 5: comparison of roughness limits



Seldom if ever can two broad-based groups, with no common membership and with different objectives, have worked entirely independently on two different standards and produced essentially the same standard: EN 13231-3 to limit irregularities that can exist on rails after reprofiling, and EN ISO 3095/prEN 15610 to state a desirable level of roughness for what is essentially a quiet or quieter railway. This unique success should be applauded, even if it was achieved by accident, and act as an example to those bodies that are responsible for standards to ensure coincidence of what is necessary, what can be measured, and what can be delivered.

Finally, I am grateful to Prof David Thompson and Dr Chris Jones of ISVR at Southampton University, who have contributed greatly to the subject of railway noise, for the use of figures 1, 2 and 3. **IRJ**