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TRACK GEOMETRY FILTERS: LINEAR-PHASE AND VERSINES.

Comparing track profiles measured with two type filter types, and with the old versine machine system.

Ray spent the major part of his career with British Rail Research in Derby and was responsible for the design of systems for automated track recording. When the original analogue equipment was updated to a digital process in conjunction with Serco RailTest (who operated the vehicles at that time), he wrote the new software package to measure the track geometry and report exceptions. This system was used for many years in the UK, known there as the Serco Lewis system. He now specialises in software applications for track recording.

INTRODUCTION

Track quality deteriorates over time due to traffic loading; to enable restoration, measurement with recording cars to establish the extent of the loss of quality is a routine procedure.

To be an effective indicator, the wavelengths present in the measured data have to be limited to those that adversely affect smooth running, both passenger and freight and for this reason, waveband filters are part of the analysis process.

Geometry filters used throughout the world have evolved and international standards now provide a means of standardisation, should railways adopt their recommendations.

INTERNATIONAL STANDARDS

The international standard: Railway Applications – Track -Track Geometry quality BS EN 13848 – 1: 2019, defines measurement techniques and filter characteristics as well as accuracy.

A significant change from older methods requires that the geometry filters should be of a non-distorting type known as 'linear-phase'. The term linear-phase may be unfamiliar to many Engineers, as indeed will be the topic of wave filters themselves. This article sets out to explain some of the differences and the extent to which they can affect the interpretation of data from recording cars.

TRACK GEOMETRY MEASURING SYSTEMS AND USAGE

A brief description of the makeup of a modern track geometry recording system is included here.

The instrumentation centres around a proprietary IMU (Inertial Measurement Unit) which contains a 3-axis accelerometer and a 3-axis rate gyroscope. This is mounted on a bogie or the body of the vehicle, together with laser scanners that locate the rail position - the top of the running table and the 14 mm gauge point.

The target for the laser has to be outside the shadowing of the running wheels, so the rail coordinates sensed are at best a sleeper pitch from the wheel load-point on the track. Thus, the measurement made is of the unloaded profile, and voided sleepers will not be pressed down at the measuring point. Sometimes, additional displacement transducers are added across the vehicle suspension to deliver the loaded profile. From the difference, voided sleepers might be detected.

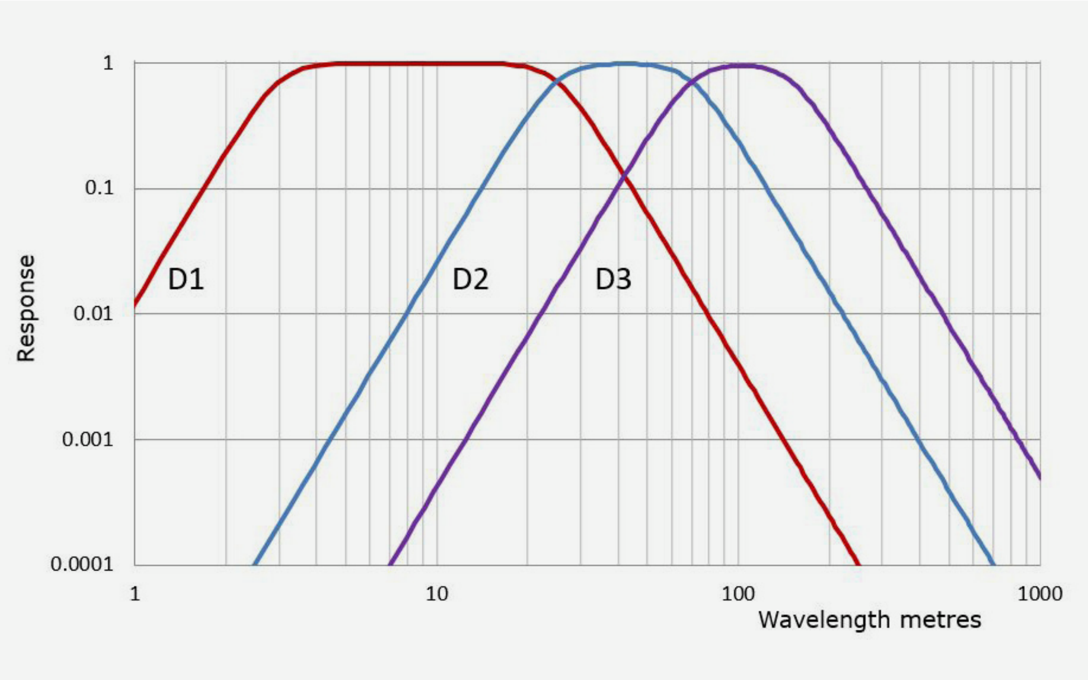

Figure 1: Response curves for EN13848 Filters

Many administrations are still wedded to measurements from the old Versine cars - their track standards are based on this flavour of measurement so a comparison with the data from these has been included for completeness.

The two main uses of data are:

- By testing against standard levels, isolated defects can be detected, categorised for severity, and remedied.
- TQI (Track Quality Indices) based on standard deviations over kilometre (or shorter as in the UK) track sections are calculated.

TQI values quantify the smoothness of the track on which the ride quality of passenger stock depends. So TQIs are a major input to the planning of maintenance machine deployment.

GEOMETRY FILTERS

EN13848 specifies filter bands and characteristics. **Figure 1** is a plot of the filters for 3 of the bands D1, D2, and D3.

The bands are defined in **Table 1** with suggested speeds for which they might be employed.

A filter is described by the sharpness in the cut-off region - the order of the filter (known as the number of poles), and the type of filter. The type specified in EN13848 are Butterworth filters named after their originator, Stephen Butterworth.

When I designed the original track recording system for BR in 1968, I chose 4-pole Butterworth filters, in two bands 35 metres (for suburban services) and 70 metres (for InterCity services) – see **Figure 2**, with a TQI based on standard deviations over 10 chain intervals.

Values of 25 and 50 metres were selected for a London Underground recording car system - shorter wavelengths because track speeds are slower.

When the EN13848 committee was formed at a later time, they chose 25 and 70 metres for the two main filters of D1 and D2. The reasoning behind the choice of two such widely spaced values was never published and now has been lost. Tablets of stone have now been chipped, I guess.

When very high-speed 350 km/hr lines were introduced by the French railways (SNCF), and later by the German railways (DB), an additional category D3 was added, which covered the much longer wavelengths for high-speed services.

FILTERS: LINEAR-PHASE AND NOT LINEAR-PHASE

The simplest type of digital electronic filter is based on the so-called IIR (infinite impulse response) configuration. This delivers its output in real-time – well maybe a few processor clock ticks later, but effectively real-time for our purposes.

IIR filters are easy to code, just a few lines in a high-level language, but there is one major disadvantage. The various wavelengths that make up the input data are shifted, or delayed, by different amounts, and whilst their amplitude is rendered correctly, the phase distortion alters the shape of features in the data.

The effect can be so severe that a feature may appear inverted so “up” becomes “down”, making a dipped joint appear as a hump – very confusing. Testing against exception levels, for filtered Vertical and Horizontal profiles is therefore less than ideal.

Another filter type can be constructed in software that does not cause this distortion, but it cannot deliver in real-time, maybe a delay of as much as a kilometre, and can only approximate to the Butterworth characteristic.

CLASS	WAVELENGTH LOW METRES	WAVELENGTH HIGH METRES	LINE SPEED KM/H
D1	3	25	<100km/h
D2	25	70	<160km/h
D3	70	150/200	>160km/h

TABLE 1: EN13848 Filter bands

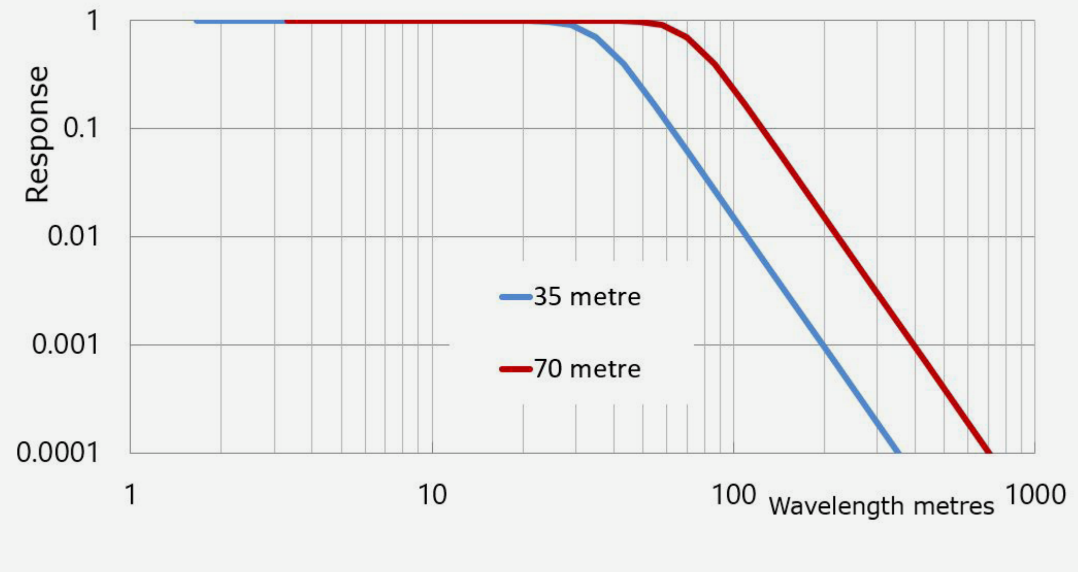

Figure 2: Inertial system filter response as used in the UK

There is however a simple and effective technique – reverse filtering, often referred to as back filtering, that offers an alternative. All that is needed is to pass the data through a half filter (2-pole), then at the end of the session pass the output from the first through a second identical filter, but this time in reverse order.

The wavelength shift in the first filter is applied in the opposite sense in the second pass, so the shifts cancel one another out.

No approximations – they cancel out exactly, but you have to wait until the end to get your data.

It will be observed that two 2 pole filters in cascade do not quite make a 4-pole Butterworth filter, but this is allowed by EN13848 and indeed is preferred.

Waiting until the session ends is no disadvantage with an unattended geometry system on passenger rolling stock.

For manned cars, there is no problem either, the two serious track defects that might need immediate action are Twist and Wide Gauge, and neither of these requires to be filtered, so both can be delivered in real-time.

EXAMPLE

Using recorded data from an anonymous standard gauge railway, three vertical profile output plots have been made for a track section of some 500 metres:

- Non-linear phase response
- Linear phase response
- Versine response from synthetic versine algorithm.

The filter used was a combination of D1 and D2 with a range of 3 to 70 metres, but applied as two half filters.

In **Figures 3 and 4** the differences in the profiles indicate the effect of the distortion. The two clearly defined dips in the linear phase true plot of **Figure 4** near the end, hardly show at all in the distorted plot of **Figure 3**. And an example of the up/down inversion can be seen about a quarter of the way along.

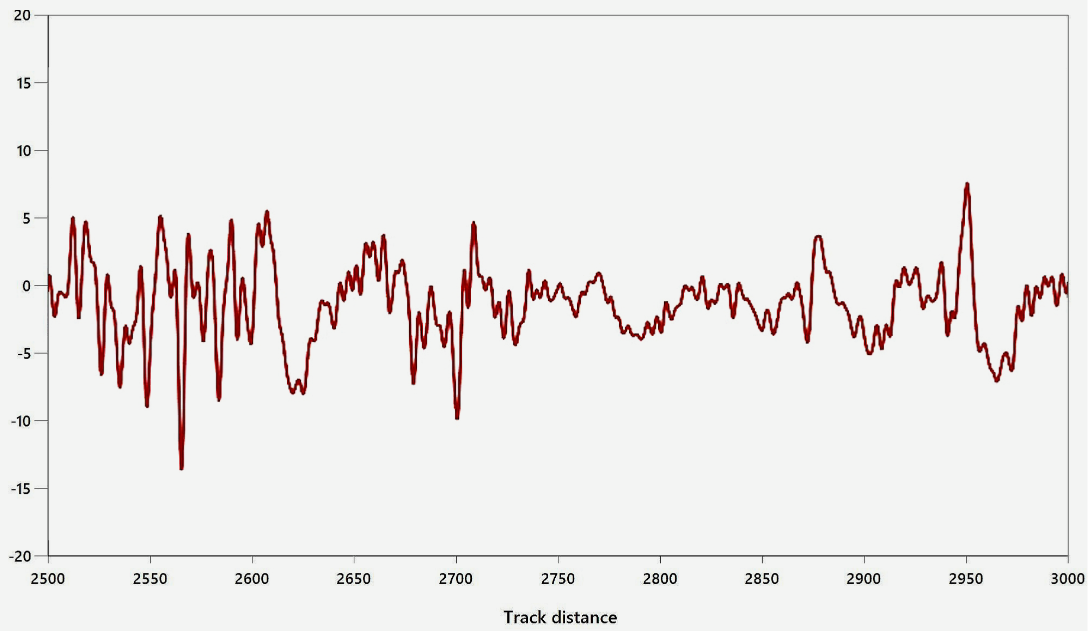

Figure 3: Vertical profile not linear phase

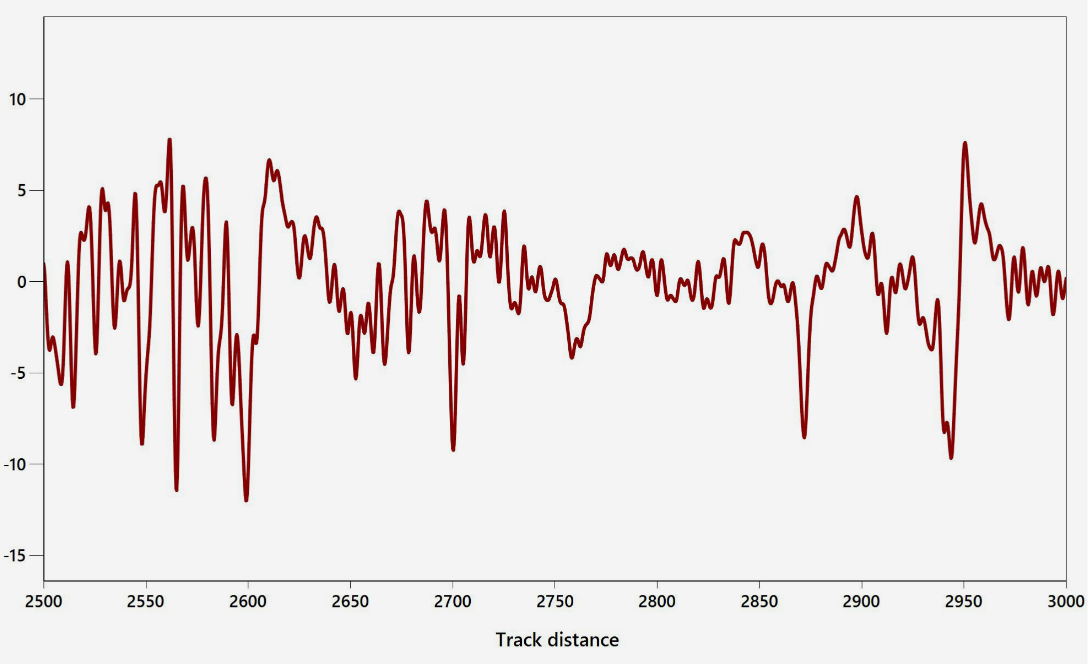

Figure 4: Vertical Profile Linear phase

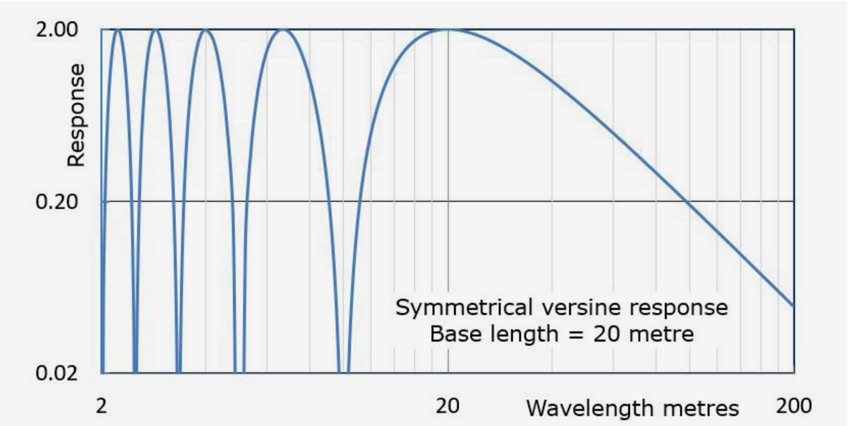

Figure 5: Wavelength plot for a 20 metre versine

But it should be said that if only distorted profiles are available, as they have been for many years because linear-phase processing has only recently started to be used, exception values are still useful and have been effective in detecting gross track defects.

And as mentioned earlier Twist and Wide Gauge do not depend on filtered channels.

Standard deviation values are unaffected by phase distortion so the accuracy of TQI plots is not dependent on linear-phase input data.

VERSINE MEASUREMENTS

The alternative form of geometry measurement, versine or chord offset was used on the early Matissa trolleys and in France on the SNCF due to the pioneering work by its later Chief Engineer: Maurice Mauzin.

The special cars, with either 3-wheeled bogies or with 3 bogies have mostly been retired, although Matissa trolleys are still in evidence in some smaller countries, and manual versine trolleys can still be found in Japan it is believed.

Because of this continued usage, it is of interest to compare versine track profiles with inertially derived ones.

Versine filters arise simply from the sensing arrangement - a rigid base with sensors picking up the rail position at three spaced points.

The wavelength response of such a system is shown in **Figure 5**, a comparison with the smooth plot in **Figure 2** will show that it is not ideal – some wavelengths are measured twice as large and others not at all, and the rate at which the response tails off for long waves is far from ideal.

The result from the test data for a 20-metre symmetric versine is shown in **Figure 6**. Because of the factor of 2, it is a bit larger than the plot in **Figure 4** but some features are similar.

Versine measurements have other drawbacks – there is no phase distortion, which is an advantage, but the simple system is not able to separate the design geometry in the horizontal plane from the variations.

Mixing up design values with deterioration values makes the data useless for machine analysis purposes. The plot in **Figure 7** illustrates this; linear-phase horizontal profile (blue trace), 20-metre horizontal versine (brown trace).

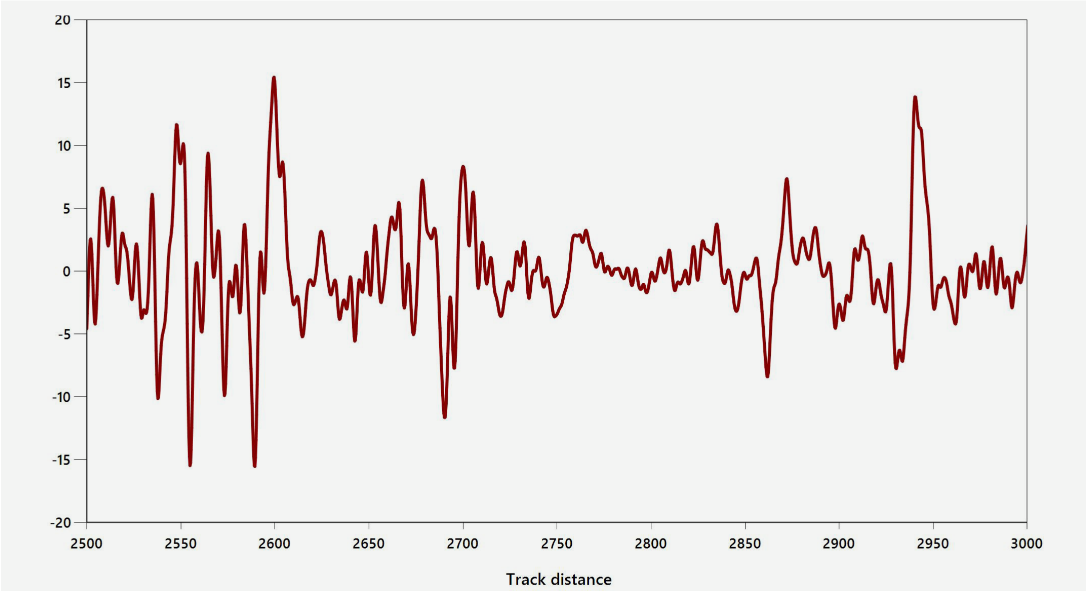

Figure 6: Vertical 20 metre response versine

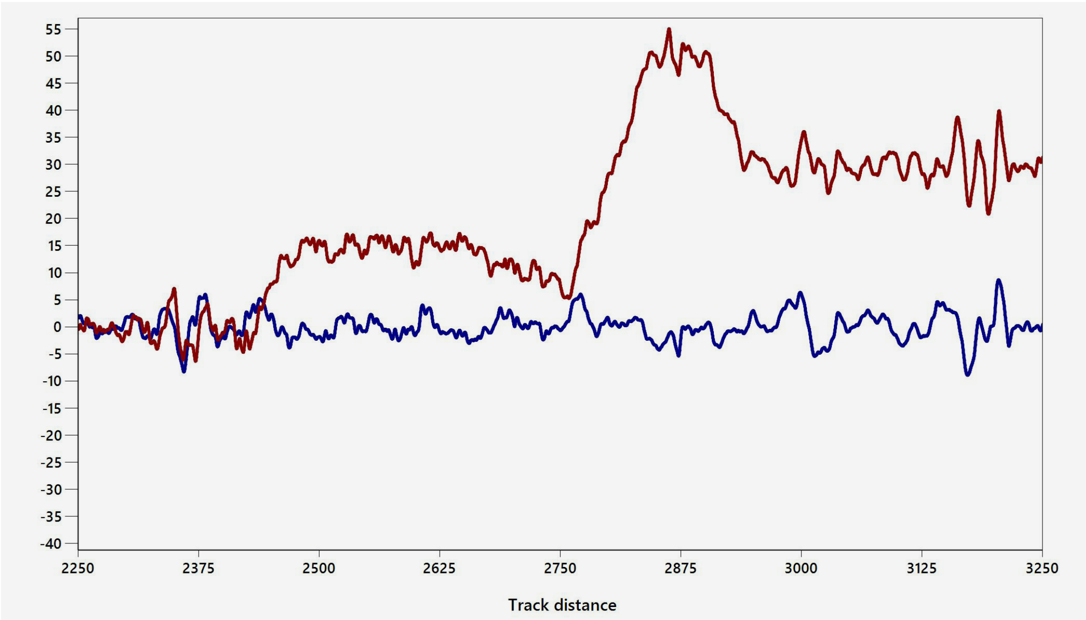

Figure 7: Horizontal Versine compared with Inertial profile

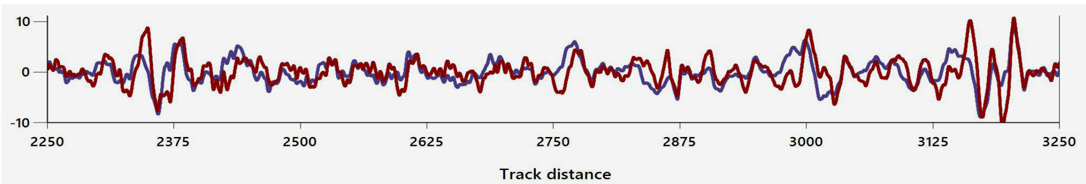

Figure 8: Versine plot with the curvature removed

As expected, the alignment or horizontal profile trace shows the variation from the design, whereas the versine trace is contaminated with the compound design curve, and this clearly shows why the versine data is completely unsuitable for TQI calculation or setting against exceptions. Although this can be done for tangent track sections.

Whereas a horizontal versine cannot be processed to remove the design component, this can be done easily when creating a synthetic versine.

This has been done **(Figure 8)** and transforms the plot of **Figure 7**, bearing in mind the two different methods there is indeed more agreement than might be expected.

By constructing synthetic versines, railways that wish to retain standards based on versine measurements may still be able to do so when their versine cars are retired.

The illustrations hopefully give some insight into differences in measuring systems, and how the differences might affect reported exceptions of vertical and horizontal profiles.

CONCLUDING REMARKS

Despite the sterling efforts of the EN 13848 committee in trying to standardise common practices, many railways, of necessity, continue with filter systems that have been in use for many years, that have served them well, and in which they have faith.

The exception levels they use are well-established and generally shown to be effective. To change to the new filters would require some new exception levels to be decided, not a trivial task, and with no immediate benefit to safety or the bottom line.

Where there are high-speed services that run across national boundaries it might be desirable to adopt a common standard for track quality.

In the meantime, there would seem to be no reason why a bit of extra code could not be introduced into existing software to produce EN13848 data in parallel with existing results at very little extra cost. The experience gained in comparing old and new systems would be invaluable if compliance with EN 13848 (or the new ISO standard due to replace it) should ever become mandated in future years.

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