Recent Trends in Track Inspection and Monitoring Technologies

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Track inspection and monitoring systems are one of the most important technologies for track maintenance. For effective and labor-saving track maintenance, several types of new system or device are being developed. In Europe in particular a number of European Norms for track inspection have been established to standardize technology so that it can be exported around the world. In this paper, the author explains recent and future trends of track inspection and monitoring technologies, with a special focus on track geometry inspection and frog defect detection systems.

**Keywords:** track measurement, rail roughness measurement, monitoring, European Norms

1. Introduction

Track deformation and deterioration occur because of the repeated passage of trains. For this reason, railway operators or infrastructure managers conduct inspections on regular basis and carry out maintenance work when needed. To this end, the railway industry has developed various types of inspection equipment, such as track inspection cars. However, in view of the expected decrease in experienced workers due to the fall in population forecast over the future in Japan, it is more than ever necessary to promote mechanization in the field of inspection and monitoring work. This paper introduces recently developed inspection and monitoring technologies to address this issue, concerning track geometry rail roughness and frogs with turnouts, and then provides an overview of the trends in this field in other countries.

This paper offers an overview of technical trends without entering the detail of individual technologies. In order to gain more in-depth information about individual technologies, readers are advised to refer to the bibliography at the end of the paper.

2. Significance of mechanized inspection and monitoring

A number of advantages can be found in conducting mechanization of inspection and monitoring work, which can be broadly summarized as follows:

1. Increase in working efficiency (reducing load on workers)
2. Accuracy improvement (making correct measurements)
3. Increase in frequency (repetition of measurement)
4. Functional improvement (measuring what human beings cannot)

The merits of (1) and (2) are evident, since mechanized differential measurements are better than manual chord measurements in the case of track geometry (track irregularity). Previously, point (3) was not regarded as critical however, with the development of various types of inspection equipment which can be mounted on commercial vehicles the importance of this aspect has grown. Higher frequency inspections, allow earlier detection of any rapid shift in the track deterioration which in turn enhances safety and greater maintenance plan efficiency. Fixed monitoring systems also belong to this category. Point (4) indicates inspection where measurement is difficult when relying only on the naked eye, e.g. measurement of rail surface roughness and internal rail defects.

As mentioned above, the overall importance of mechanization is clear, but benefits it brings to measuring will vary depending on the applied system. When developing a new technology, it is necessary to consider what the expected merits will be.

3. Inspection of track geometry

3.1 Track measurement

Among the various track geometry types of inspection, one targeting so-called track irregularity is usually called “track measurement (or simply “measurement”). Track measurement focuses on five items: longitudinal level, alignment, cross level, gauge, and twist. Among them, the latter three items are related to the relative position of both rails; the basic method used for each measurement is identical in Japan and overseas. On the other hand, longitudinal level and alignment refers to the geometry in the longitudinal direction each of the two rails, for which...
some different measurement methods are used as shown in Fig. 1. In Japan the ‘versine’ method, a kind of second-order differential method, has been used since railway operation started in the country. The track inspection car used for this method needs three pairs of measurement devices arranged at regular intervals (usually 5 m). A representative example of this type of inspection car is the Maya-34, developed by the former Japanese National Railways, and the No.11 of the Class 921 (former Doctor Yellow) used for Shinkansen lines.

Problems however sometimes occur on the middle bogie of the 921-11 and other three-bogie type track inspection cars, in terms of running stability at high-speed. Therefore, a two-bogie track inspection car was developed which allows the two-bogie structure used in commercial vehicles and employs the asymmetrical chord offset method. The first model of this type of track inspection car was the No.32 of the Class 921 designed for the East Japan Railway Company Tohoku, Joetsu, and Nagano Shinkansen lines, in 1997, which today has become mainstream. Though the measurement principles it applies are based on asymmetrical chord offset, its output applies the 10 meter-chord versine method and a system of track maintenance is the same as before.

In Europe, the mainstream type of track inspection car in the past was based on the differential method, like in Japan, but today European infrastructure managers use, more often than before, track inspection cars functioning with the inertial measuring method. This trend probably stems from a number of advantages to be gained using the inertial measuring method: only one pair of measuring devices is required and there is a higher degree of freedom in attaching the device to a vehicle. In addition, the European railway sector has specified, in the standards EN13848-5, values for action for track maintenance (correctly the immediately action limit) using actual amplitude. When applying actual amplitude, an output can be used, as it is, in measurement with the inertial measuring method. When using the differential method however, it is necessary to do re-colouration processing against an output, subject to measurement properties. For this reason, it is expected that European railway operators will accept the inertial measuring method as a prerequisite not only for selecting a measurement method but also for considering management methods. In Japan, all the railway operators specify values for maintenance action concerning longitudinal level and alignment using the 10 meter-chord versine method. And it is one of the reasons why the inertial mid-chord offset method, which will be explained later, is needed. Incidentally, mandatory specifications for track inspection cars in Europe have been stipulated in EN13848-2, preparing the way toward standardization in this area, too.

Track inspection equipment based on the inertial measuring method has in the past also been developed in Japan. However, those developing this equipment found the waveform distortion accompanying two-step integration undesirable, and this technology was therefore only allocated a backup role to support track inspection cars (where the differential method is adopted) that was regularly operated in a series of inspections.

A track inspection system based on the inertial measuring method was first used in Japan for periodic inspections with the inertial mid-chord offset method, which had regularly been adopted in a series of inspections on the Kyushu Shinkansen line since 2009 (Fig. 2). In terms of measurement principles, the inertial mid-chord offset method is similar to the conventional inertial measuring method. However the former is characterized by application of filtering with features of the versine method to a process of two-step integration. With this method, the unwanted waveform distortion can be avoided and, at the same time, the conventional action values for track maintenance can be adopted, unchanged, because the output waveform is compatible with the 10 meter-chord versine method. In addition, output from the 10 meter-chord versine method includes information about radius, allowing the output to be used in curvature form control. Generally speaking, the inertial measuring method cannot output information about the radius, so that track inspection cars used in Europe use the bogie-yaw angle and other data to complement this disadvantage.

It is possible to attach a track inspection system to an ordinary vehicle for commercial use, that functions by inertial mid-chord offset method and, what is especially needed is a car-body mounted type of this type of system. Based on this merit, application research has been pursued on how to use vehicles for commercial use in highly frequent track measurement.

### 3.2 Rail roughness measurement

Rail roughness measurement is important in order to prevent ground vibration and noise generation along railway lines or damage to tracks caused by impulsive wheel loads. Specifically, the following methods are used to measure rail roughness:

1. **Methods using axle box acceleration or under-car body noise**

   Compared with track displacement, rail roughness is very small, i.e. in the region of 1/100 to 1/1000 in amplitude, making direct measurement of rail roughness from an on board device difficult. To address this issue, several methods to indirectly measure rail roughness have been developed. One of them uses axle box acceleration. Efforts to apply this method to detection and verification of rail unevenness began at the time of Japanese National Railways, and research in this field has been deepened as the speed of Shinkansen trains increased, in the period after

![Fig. 2 Inertial mid-chord offset track inspection system (Kyushu Shinkansen)](image-url)
the privatization. Today, there are many track inspection cars equipped with axle box accelerometers to measure rail roughness. It should also be noted that railway operators have long used a verification method that focuses on under-car body noise generated on vehicles running on rough rails. Track inspection cars on Shinkansen lines have measured under-car body noise since the time of Japanese National Railways.

Axle box acceleration and under-car body noise are however strongly affected by roughness of wheels and train speed, hence data for these two factors have little reproducibility. Railway operators therefore collect these measurements, but don’t use this data effectively for any other practical purpose. Nonetheless, even if these disadvantages are taken into account, axle box acceleration and internal noise can be easily measured even in cars for commercial use; in addition, if measured data is processed properly, it is possible to grasp correctly not only rail roughness but also the condition of the rail support (whether or not loose sleepers are used, etc.) and other response values such as wheel load/lateral force, and rolling noise. Accordingly, further application of such data is desirable in future. The Railway Technical Research Institute is engaged in development of a system to detect and evaluate rail roughness through measurement of floor noise inside the cabin of a commercial use vehicle using a portable sound level meter. In parallel, a joint research group established by the Nihon University and Independent Administrative Institution National Traffic Safety and Environment Laboratory has also developed similar equipment.

(2) Rail roughness measurement systems

This section focuses on equipment for the direct measurement of rail roughness as opposed to indirect quantities such as axle box acceleration and under-car body noise. Europe has standardized basic specifications and data processing methods for this type of measurement equipment in EN13231-3 and EN15610. They adopt, as a basic principle of measurement, one of the methods indicated in Fig. 1, though they have different wavelength bands. Figure 3 shows a system developed by the Italian MERMEC S.p.A, which is called the Rail Corrugation System (RCS). The system has four pairs of optical non-contact displacement meters setup on the hidden side of a screen functioning as a sunlight shielding. It measures roughness of a rail using the asymmetrical chord offset method. In Europe, in addition to this product, various types of rail roughness measurement systems have been commercialized. This demonstrates Europe’s strong will to reduce rolling noise.

In Japan, similar types of equipment have been developed, too. For example, the Railway Technical Research Institute is engaged in designing a trolley type system using the asymmetrical chord offset method. This system adopts the asymmetrical chord offset method to avoid a wavelength band where the gain falls to zero. Furthermore, the structure enables adjustment of the sensor position to the direction of a rail section. With these features, it can measure a waveform representing rail roughness at a location other than the center of the top surface of a rail, which is similar to rail corrugation that is generated at the gauge corner of an outer rail in a sharp curve.

4. Continuous monitoring of track at fixed points

4.1 Significance of track state monitoring at fixed points

As a track is provided continuously in a direction of roadway, independent-minded development has been pursued to design measurement equipment that can make continuous measurement, no matter if it is used in a special vehicle, a vehicle for commercial use, a maintenance car, or a trolley car. On the other hand, when targeting track equipment, such as a turnout, which are only in stations or depots and require large labor resources to make measurements due the deteriorated state of the structure, running safety could be vastly improved and inspection costs lowered if continuous measurement of deterioration was possible using sensors or similar devices, installed on the track side. This chapter will introduce two examples of monitoring technologies for turnout crossings, which the Railway Technical Research Institute has developed recently as well as a technology development trends in other countries on field position monitoring.

4.2 Monitoring of swing Nose crossing

A swing nose crossing made of manganese steel is a cast element where blow holes may exist; due to these holes, it is difficult to detect internal flaws through ultrasonic testing. For this reason, an actual inspection is conducted by applying a liquid penetrant inspection or a visual check, which requires a large amount of labor. To address this issue, the Railway Technical Research Institute has developed a new method using electrically-conductive coating to detect fatigue cracks generated in a swing nose.

Figure 4 is a schematic diagram of this method. Thick modified epoxy resin-based coating, effective for both insulation and corrosion prevention, is applied to the location where a crack is supposed to occur, and then linear or belt-like electrically-conductive coating is applied on it. When a crack is occurs on the base material, the linear conductive coating film is broken, and the electric resistance of the coating film changes. By detecting this change, it is possible to detect cracks. Moreover, with progress of cracks on the basic material, electrical resistivity of the part with belt-like coating changes gradually. By detecting this change, insight is gained into crack development.

This procedure was applied and tested on a commercial line to verify its basic performance, namely crack detection.
durability of coating, influence on other types of maintenance work, etc.

In the case of a frog, other kinds of damage occur in addition to fatigue cracks. Specifically, a rigid crossing tends to suffer damage due to impulse loads on the section where wheel transfer occurs, between the wing rail and nose rail. To address this issue, the Railway Technical Research Institute is now developing a method to detect the occurrence and progress of defects by monitoring changes in the dominant frequency and vibration levels through measurement of vibration acceleration at each part of a frog when a vehicle passes over it.

Figure 5 shows a 1/3-octave frequency band of vibration acceleration at a frog that is measured inside the gauge around the toe of a rigid crossing nose at the time when a vehicle is running in the trailing direction. The Figure shows results from two cases where a new crossing is used, and when a defect is simulated with a metal plate. This Figure shows a shift of the dominant frequency toward a higher pitch from 80 Hz to 1250 Hz and, at the same time, an increase in the vibration level by 10 dB to 30 dB. In this method, if the traveling position of a wheel changes, a difference emerges in vibration acceleration. Therefore some contrivance is necessary in processing measured data. The author expects to fix this issue and others and complete this method as an effective method to monitor a crossing.

The European railway industry is also tackling various R&D activities focused on turnout monitoring. For example, parties involved in INNOTRACK, EU’s technology development project concerning track maintenance, are discussing technical specifications for a failure detection system for turnouts. While specifications are discussed, studies are also being made on how and what targets should be measured in monitoring sets of points, locking devices, and other track installations. And together with it, they introduce monitoring devices actually in use in EU member countries. This report is publicly available on the Web site.

5. Conclusions

This paper briefly introduced recent trends on track inspection and monitoring technology. It also mentions the fact that the European railway sector has formulated various standards related to track inspection, with a view to promote the adoption at a global level of European standards not only for inspection equipment and other types of hardware but also for software, namely management methods.

Today the Japanese Government and railway industries have the vision of expanding its own railway technologies overseas. However, the Japanese railway sector has no unified standards and specifications for operation and maintenance of tracks aside from ministerial directives and governmental regulations, and the specific contents of these directives and regulations are not yet known to or accepted by other countries. In reality, when exporting railway technologies, Japanese manufacturers are often requested to conform to international standards. For example, for matters not specified in ISO or IEC, it is not rare that an EN applies even in non-European countries, as if ENs were de facto international specifications. Consequently, the most important challenge is to raise Japanese track maintenance methods (both in hardware and software) to international standard status, for example, through the offices of the ISO/TC 269 technical committee formed in 2012. In other words, Japanese track maintenance technology has to be exported via the 'standards' route.

It should be also noted that other types of track inspection and monitoring technologies have been developed, in addition to those presented in this paper. Track component inspection technology supported by image processing in particular has advanced remarkably over recent years. The author is looking forward to another occasion to make a report on such technologies.

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