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RCM^2 predictive maintenance of railway systems based on unobserved components models

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Abstract

Turnouts are probably the most important infrastructure elements of the railway system because of its effect on the system safety, reliability and quality of the service. In this paper, a predictive maintenance system in point mechanism, called RCM^2, has been implemented for increasing the quality service. RCM^2 is based on the integration of the two other types of maintenance techniques, namely Reliability Centred Maintenance (RCM_1) and Remote Condition Monitoring (RCM_2). The core of the system consists of an Unobserved Components model set-up in a State Space framework, in which the unknown elements of the system are estimated by Maximum Likelihood. The detection of faults in the system is based on the correlation estimate between a curve free from faults (that is, continuously updated as new curves are incorporated in the data base) with the current curve data. If the correlation falls far from one, a fault is at hand. The detection system is tested on a set of 476 experiments carried out by the Universities of Sheffield and Castilla-La Mancha.

Keywords: Turnouts; Points mechanism; Quality service; Remote condition monitoring; Maintenance; State space; Kalman filter; Fixed interval smoothing; Maximum likelihood; Reliability

1. Introduction

The Railway transport system is experimenting a deep transformation nowadays. The main causes are, basically, the launch of high speed trains, high traffic levels in metropolitan areas and the restructuring of railway companies. The introduction of high speed networks and increased traffic levels require new technologies in railway infrastructure and trains, which must go through a rigorous control of quality service and maintenance processes during their operative lives. On the organisational side, the current process of restructuring, especially in Europe, is being regulated by new legal directives, mainly about competition and safety. The most recent European Directives about safety in railway transport are 2001/12/EC [5], 2001/13/EC [6] and 2001/14/EC [7]. Therefore, the gathering of equipment, people and procedures which work together to achieve a common goal must adjust to the new changes.

Safety in railway infrastructure must be understood as the safe performance of their functions by the main components [15,16]. From an economic, quality and safety point of view, turnouts are certainly one of the most critical infrastructure elements in railway transportation [25,29]. A predictive maintenance system, based on RCM^2, is developed in this paper for these critical elements. The main purpose of the system is to detect possible failures in advance in order to reduce to an acceptable level, or to eliminate, the likelihood that an accident will happen as well as minimising the damage it could produce.

RCM^2 is a combination of the principles of Reliability Centred Maintenance (RCM_1) [22] and Remote Condition Monitoring (RCM_2) [30], see Refs. [9–12,21,26]. RCM^2 is presented here as a technique which can support a railway safety case, in which the European standards for railway applications published by CENELEC (see, e.g. Refs. [2–4]) and the IEC Standard 61508 [17] (which includes analysis of hazard and risk) have been taken into account. It is a technique that takes advantage of know-how in electronics,

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control, computing and communication technologies to address the multiple objectives of cost effectiveness, improved quality, reliability and services.

The main hazards considered in the experiments carried out for this paper have been identified and analysed, with the intention of taking specific action to avoid them or to reduce the risk related to them, and a new algorithm for detecting these hazards has been developed, based on prediction in real time. The system is of the Unobserved Components (UC) class, implemented within a State Space (SS) framework. In essence, it searches for significant correlations between a reference curve and the new information coming from the critical components. The model parameters are updated on a continuous basis each time new data becomes available. The system developed has been tested in numerous experiments to show its efficiency. This system is able to find potential hazards, but the organization for the maintenance of the turnouts must set safety requirements for any change, to reduce the risk associated with the change to an acceptable level, carrying out an adequate safety plan according to regulations and relevant standards.

2. Point mechanism

Approximately 55% of railway infrastructure component failures on high speed lines are due to signalling equipment and turnouts [24]. 'Signalling equipment' covers signals, track circuits, interlockings, automatic train protection (ATP) or LZB (track loop-based ATP), and the traffic control centre. From another point of view, the annual cost of maintaining points is rather high compared to other infrastructure elements, about 3.4 million UKP (United Kingdom Pound) per year for about 1000 km of railway. TC-TCR trade circuits, for example, cost 2.1 million UKP per year for the same area. Of the points expenditure, 1.2 million UKP is for clamp lock type (hydraulic) turnout and 1.4 UKP million for electrically operated turnouts (data provided by a British asset manager). Turnouts can also be used to implement flank protection for a train route allocated to another train. This is achieved by positioning the blades of the turnout in such a way that a train driving through the turnout is not directed into a track segment belonging to the route of another train.

Most standard point machines (see Fig. 1) contain a switch actuating and a locking mechanism which includes a hand-throw lever and a selector lever to allow operation by power or hand. The mechanism is normally divided into three major subsystems: (i) the motor unit which may include a contactor control arrangement and a terminal area; (ii) a gearbox comprising spur-gears and a worm reduction unit with overload clutch; and (iii) the dual control mechanism as well as a controller subsystem with motor cut-off and detection contacts. Generally, there are also mechanical linkages for the detection and locking of the point. The standard railway point is, therefore, a complex

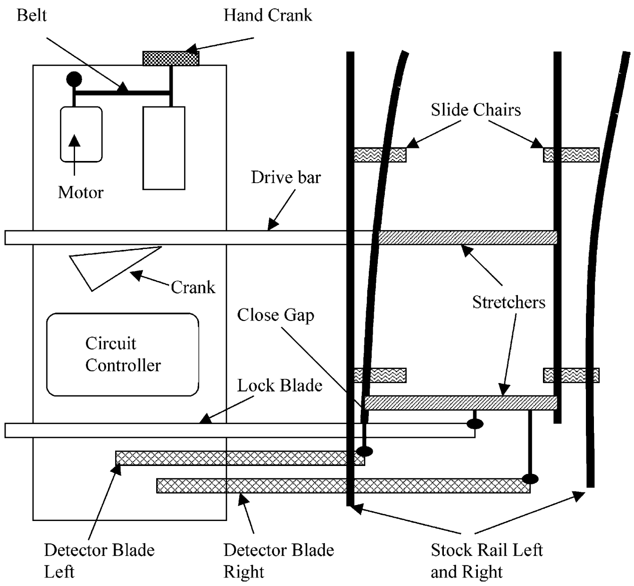

Fig. 1. Point mechanism.

electro-mechanical device with many potential failure modes [28].

In the experimental set-up used for the present experiments, the motor current is measured using non-intrusive current transformers mounted within the point machine housing. The current transformers are toroidal coils through which the common return wire from the motor passes. The force in the drive bar is measured with a load pin. This is inserted in place of the bolted connection between the drive bar and the drive rod. This component carries Railtrack approval and can thus be used on points, which are in service.

3. Data analysis

Four hundred and seventy six experiments (points moves or attempted point moves) were carried out while collecting time, force and operating current data. Several faults were intentionally provoked in the experiments in order to test the system response to different fault causes. This is similar to a system used in research work carried out for the Tokaido Shinkansen of the Central Japan Railway Company as part of their CTC and Computerised Traffic Control System (COMTRAC) [28]. The data from the point mechanism are initially classified in terms of direction of movement, i.e. either reverse to normal direction or normal to reverse direction.[1] For both directions, faults have been detected with 'current (A) vs. time (s)' curves and 'force (N) vs. time (s)' curves (see some examples in Fig. 2(a) and (b)). It was observed that 'current (A) vs. time (s)' curves are not the best choice for detecting faults in point mechanisms.

[1] The turnout has moving parts which are called blades and which steer the trains in one of two directions, normal (straight through) or reverse. The blades move from normal to reverse or reverse to normal direction.