Available online at www.sciencedirect.com
SCIENCE DIRECT
Control Engineering Practice 14 (2006) 885–895
CONTROL ENGINEERING PRACTICE
www.elsevier.com/locate/conengprac

Detection of incipient failures by using an H_2-norm criterion: Application to railway switching points☆

Elena Zattoni*

DEIS, University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy

Received 25 April 2004; accepted 3 May 2005
Available online 5 July 2005

Abstract

The paper deals with condition monitoring of electric switch machines for railway points. The proposed detection system is based on off-line processing of armature current and voltage sampled as the machine operates a switch of railway tracks. These data are normally available from conventional railway signalling infrastructures; no additional transducers and instrumentation are required. The system, which basically consists of an algorithm tuned on a model of the machine behaviour as both the rails are simultaneously driven towards their rest position, allows detection of faults of an incremental nature, specifically those connected to progressive increasing of frictional loads due to loss of lubrication, deterioration of slide chairs and increasing obstructions. The algorithm implements finite impulse response systems whose convolution profiles are designed on the basis of an H_2-norm type criterion which guarantees robustness, particularly with respect to electrical noise.

Keywords: Linear systems; Fault detection; H_2-optimization; Railway points

1. Introduction

Economic and environmental reasons have recently forced railway infrastructure administrations to invest more in research and development items, in order to optimize their supply. This process has evolved in two different directions. The first is the production of new generations of trains and railway systems based on the utilization of new technologies. For instance, advanced automatic train control requires accurate measurements of position, speed, and acceleration: these are obtained through a complex architecture of different sensors and then processed along with other information stored in the memory of the control system like, e.g., routes and timetables (Mirabadi, Mort, & Schmid, 1996). The other direction is the improvement of existing conventional infrastructures in order to reduce maintenance costs and, possibly, provide a higher level of reliability and safety. In this context, special attention is paid to railway signalling equipment, which failure statistics have shown to be responsible for a remarkably high number of service disruptions and delays (Railtrack, 2001). In particular, studies focused on databases of conventional railway signalling failures carried out in different countries have shown that the reliability of railway points is crucial to service efficiency (IRSE, 1994; SASIB, 1994). According to SASIB (1994), signalling failures caused by electric point machines amount to about 15%; among them, those attributable to faults of an incremental nature (e.g., lack of lubrication and obstructions) amount to about 36%. Actually, the use of well-proven components combined with frequent site visits and planned maintenance has enabled a good standard of quality to be achieved. However, service disruptions and safety concerns related to on-site inspections along with rising costs of qualified workforce on the one hand and progressively decreasing costs of microelectronics and information technologies on the other hand have induced railway

☆This paper was not presented at any IFAC meeting.

*Tel.: +39 051 2093023; fax: +39 051 2093073.
E-mail address: ezattoni@deis.unibo.it.

0967-0661/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conengprac.2005.05.004

infrastructure management to evaluate the possibility of implementing large-scale computer-based condition monitoring. Quantitative benefits of condition monitoring combined with condition-based maintenance consist in reduction in repair and maintenance costs, reduction of spare inventories and increase in plant profitability (SOLARTRON, 1994). Thus, a great deal of research effort has recently been directed towards condition monitoring and fault detection for railway point machines, see e.g. (Oyebande & Renfrew, 2002; Roberts, Dassanayake, Lehrasab, & Goodman, 2002; Zhou, Duta, Henry, Baker, & Burton, 2002) and references therein. Although each of the abovementioned articles proposes an original solution, they all share the same off-line option, which neatly distinguishes their approach from those more often encountered in the specific literature on fault diagnosis. In fact, most fault diagnosis systems (and, mainly, those devised first) operate on wide industrial plants or complex processes and systems, like e.g. nuclear power plants (Kitamura, 1980; Weerasinghe, Gomm, & Williams, 1998), chemical and petrochemical processes (Himmelblau, 1978; Morris & Martin, 1996), aerospace control systems (Friedland, 1982; Laplante, 1993). Since in those applications safety and quickness of intervention are a must, fault diagnosis is carried out by highly sophisticated real-time systems. In conventional railway point machines, as well as in many other electro-mechanical assets like lifts and automatic doors and barriers, a simple emergency device causes immediate and safe service disruption in case of failure. Thus, a low-cost off-line condition monitoring system whose objective is detecting anomalies which would turn into failures in the long term appears to be the most appropriate solution. In Roberts et al. (2002), fault detection and isolation of point machines detached across a geographical area is attained through a multilevel architecture including the first level of transducers and fieldbus networks, the second of local asset embedded processors and the third of the area maintenance information system. Fault detection is based on abstract static models, while isolation is achieved by resorting to neuro-fuzzy networks. In Zhou et al. (2002), fault detection and prediction is achieved by processing a wide variety of information: driving current and voltage, electrical noise, temperature, motor driving force, time stamping of point operations, loss of power supply, etc. Data processing consists of both event analysis, which focuses on peculiar parameters of the plots of the variables considered, and data trend, which searches the plots for variations which can lead to failures. In Oyebande and Renfrew (2002) condition monitoring is based on a net energy analysis technique: robustness of this method relies on the use of two different types of waveforms (armature current and voltage), so that random fluctuations in one have less effect on the overall result.

The detection system proposed in this paper has in common with the articles quoted above the same option for off-line processing. However, it totally differs in the methodology adopted to design the detection unit, whose job is, as aforementioned, to detect faults of an incremental nature by using recorded sequences of armature current and voltage, in the possible presence of electrical noise. The methodology arises from the geometric approach to fault detection and to the dual problem of noninteraction (Basile & Marro, 1970, 1992; Massoumnia, 1986; Massoumnia, Verghese, & Willsky, 1989). However, optimization techniques are adopted, since, as can be easily verified, exact conditions for structural fault detection and isolation are not satisfied by the system under investigation. In particular, an H_2-norm criterion appears to be particularly convenient, since it can straightforwardly be expressed in the time domain, thus allowing the problem to be completely treated in the state space. By suitably adapting a procedure also suggested in Frank & Wünnenberg (1989), the performance index is defined as the ratio of the L_2-norm of the outputs of the observer unit due to the fault input and the noise, respectively. Thus, the residual is optimal in the sense that the effects of the fault are maximal with respect to the effects of the disturbance, which also implies that the detection system has some robustness properties with respect to the disturbance. Several features distinguish the present approach from that of Frank & Wünnenberg (1989). First, the design of the observer units is carried out in the dual setting of noninteraction: as the investigation of exact conditions was first performed in the control field and then transferred to observation, it seems convenient to follow the same track also in the investigation of optimization techniques. Moreover, the design of the noninteracting control units is based on an H_2-norm type approach which also takes into account the main constraints introduced by practical implementation requirements: (i) finite control horizon; (ii) finite control energy; (iii) zero final state. Finally, the algorithmic implementation of these units is achieved through nonconventional devices such as finite impulse response systems.

Notation: $\mathbb{Z}$, $\mathbb{Z}^+$, and $\mathbb{R}$, respectively, stand for the set of integer numbers, the set of nonnegative integer numbers, and the set of real numbers. Matrices and linear maps are denoted by slanted capitals like A. The symbols $\ker A$, $\mathrm{tr}(A)$, $A^\top$, and A^{H} are, respectively, used for the null space, the trace, the transpose, and the complex conjugate transpose of A. The symbols I and O are, respectively, used for an identity matrix and a zero matrix. For a vector $u \in \mathbb{R}^n$, the symbol $\|u\|_2$ denotes the Euclidean norm. For a stable discrete-time transfer function matrix $G(z)$, the symbol $\|G(z)\|_2$ denotes the H_2 norm. The symbol $\delta(t)$ denotes the unit pulse sequence.