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Continuous Time Parameter Estimation Method for a Railway Track Switch Actuator

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***Abstract*—The scheduled maintenance procedure required for the safe running of a switch system is costly and often involves large time. In the changing rail network, the scheduled maintenance process is needed to be replaced with advanced condition monitoring approaches which can predict and detect degradation in the system performance and notify the operator. The present research addresses the challenge to detect any degradation or change of performance of the switch actuation system using continuous time parameter estimation method. A switch system with an electro-mechanical actuator has been considered and the developed technique is tested with changing switch parameters. A new switch actuator is now built and validated and installed in a working test switch system. The method will be tested for different unhealthy/fault scenarios with the working actuator connected to a working switch system**

***Keywords*— Condition monitoring, Continuous time parameter estimation, Refined instrumental variable method, Railway track switch**

I. Introduction

Railway track switches are safety-critical assets of the rail network which helps the rail vehicles to change tracks. It is therefore very important to monitor the system characteristics and performance to prevent any failure of the switch system. The most common method of the maintenance carried out in the rail infrastructure companies is the scheduled maintenance process. However, this process is costly and time-consuming [1-2]. Predictive maintenance improves the performance of the switch system by inspecting some parameters of the system during a regular inspection [3-6]. But with the increased number of the high-speed train and increased density of the trains in the network, the time available for the scheduled maintenance is also very limited. Thus, condition monitoring of the switch systems is of high importance for the safe running of the network.

The parameter estimation of a dynamic system based on mathematical models is well researched in different applications. The two distinct approaches in the parameter estimation technique are continuous time and discrete time parameter estimation. Although the dynamic systems are in a continuous time domain, the research on discrete-time models has been explored much more than the continuous-time methods. However, continuous time parameter estimation techniques were not explored much in railway applications. This research focuses on continuous time parameter estimation techniques applied to a track switch system. The Instrumental variable (IV) technique to estimate a system parameter is used in many applications [7-10]. An iterative Simplified Refined Instrumental Variable (SRIV) method of parameter estimation for continuous time systems, which is widely used [8.11], is applied in the present application.

This paper explains the phase of the work carried out within the project S-CODE [12]. In this study, first, a dynamic model of the switch actuator is developed and the parameter estimation method is included with the model. This section also discusses the tests and validation of the parameter estimation method when applied to a validated multibody simulation model prepared using Simpack. The next section explains the experiments which are being carried out with a switch actuator till now and the future plan of this research.

II. Mathematical Modelling

A. *Modelling of the Switch*

The methodology followed in this study is divided into three phases. In the first phase, a mathematical model of the system is developed and a continuous time parameter estimation method is developed. In the second phase, to check the performance of the derived technique a multibody simulation (MBS) model is constructed. Different fault scenarios are simulated through the MBS model and are validated with the parameter estimation technique developed in the first phase. The third phase of the research focuses on a laboratory experiment. In this phase, a validation of the mathematical model with experiments on a full-scale switch system is performed. The next part of this phase will focus on the validation of the estimation technique when fault scenarios are injected in the switch system.

A conventional switch and crossing (S&C) system is shown in Fig. 1. The electromechanical actuator, used in this research, includes an electrical motor and gear-box assembly which is connected to a ball-screw with a short shaft (Fig. 2). The governing equation of the actuator has been derived from using the method discussed in [13]. The two sensors connected to the actuator are the motor current sensor and LVDT connected at the front toe to measure the displacement of the switch rails. The governing equations of the actuator have been simplified as (1).

$$J_T\ddot{\theta} + K_F\dot{\theta} + K_{sp}\theta = K_T I_M \quad (1)$$

where, $\theta = 2\,\pi\, x_{ft}/l$

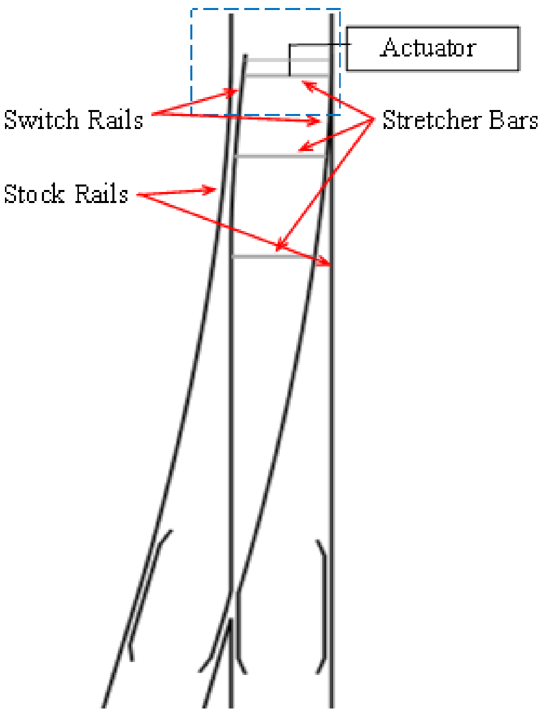

Fig. 1 The switch Layout

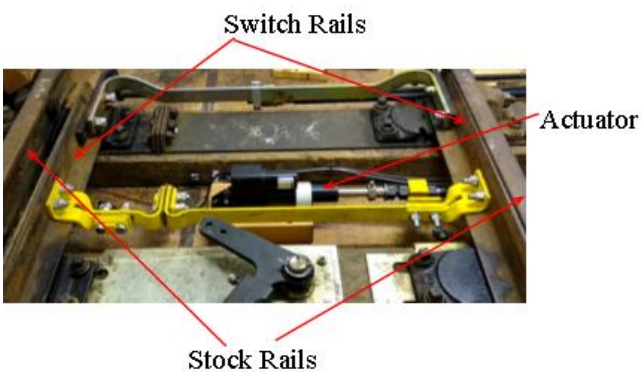

Fig. 2 The Electro-mechanical actuator installed in the switch at the BCRRE, University of Birmingham

TABLE I. PARAMETERS OF THE SWITCH SYSTEM

Parameter	**Description**
θ	Angular rotational of the lead-screw
x_{ft}	The linear displacement of the lead-screw
I_M	Armature current of the electric motor
K_T	Torque Constant of the electric motor
K_{sp}	Equivalent spring stiffness of the rail
K_f	Equivalent viscous friction of the system
J_T	Total inertia of the system
l	A lead of the ball-screw

The parameters are listed in Table 1. A multibody simulation model of the working switch system, which is previously developed and validated in [13], is connected to the actuator model. The full system is simulated for different healthy and faulty scenarios by varying parameters in the Simpack and Simulink models.

B. Continuous-time Parameter Estimation Technique

The sensor output available from the switch system are the current sensor which measures the current input to the electrical motor and a linear potentiometer to measure the linear displacement of the switch rails at the switch tow. The transfer function of the system can be written in the form of a continuous time transfer function to achieve an input-output relationship as (2) and (3).

$$T(s) = \frac{x_{ft}(s)}{I_M(s)} = \frac{\frac{(l/2\pi)K_T}{J_T}}{s^2 + s\frac{K_f}{J_T} + \frac{K_{sp}}{J_T}} \quad (2)$$

or,

$$T(s) = \frac{B(s)}{A(s)} = \frac{b_0}{s^2 + s\,a_1 + a_0} \quad (3)$$

Any change in these four parameters K_T, K_{sp}, K_f and J_T may occur during the operating period and can be reflected with the changes in the three estimated coefficients b_0, a_0 and a_1. The three estimated b_0, a_0 and a_1 directly relates the physical parameters K_T, K_{sp}, K_f. If the three estimated coefficients change, then it can be concluded that this is due to the change in the value of J_T.

C. Multibody Simulation model

The first phase of the work was to develop a multibody simulation model of the switch system using Simpack to check the performance of the system and validate the model. To model the switch system, the bending of the rail elements is needed to be modelled first as the switch rails are bent during the switching period to complete the action. The modelling concept used in [13-14] is used in this work to develop the Simpack model shown in Fig. 3 where the rail elements are flexible bodies created through Finite Element software Abaqus. The full-switch system is constructed through a co-simulation environment between the Simulink model (actuation and control) and the Simpack model (switch panel element).

In this simulation work, only one fault parameter is studied which is the change in friction. The friction of the system can be altered over a long time of operation due to environmental effects or changes in the sliding surfaces. In this scenario, one healthy and four unhealthy test cases were generated by changing the friction coefficient between the sleepers and the rails in Simpack (as shown in Table 2) and the parameter estimation technique is tested.

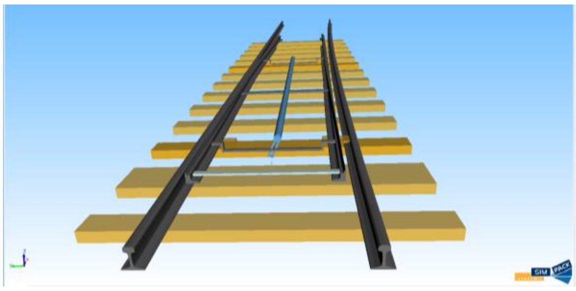

Fig. 3 MBS model of the switch system developed in Simpack

TABLE II. FRICTION COEFFICIENT VALUES FOR THE HEALTHY CONDITION AND FOUR UNHEALTHY CASES

Parameter	**Value**
Case 1 (healthy)	0.001
Case 2	0.0035
Case 3	0.006
Case 4	0.0085
Case 5	0.011

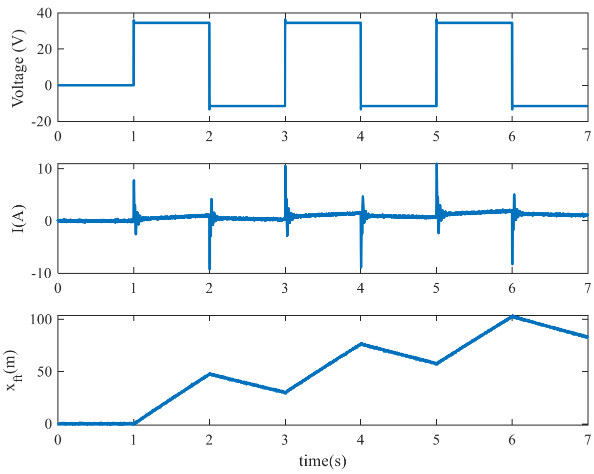

Fig. 4 Response of the system in the healthy case (Case 1)

The residuals of the system output (y_k) and the output of the same in healthy condition (y_{kh}) are plotted in Fig. 5, where k represents the index of the signal following (4). It can be seen that the signals of motor current and displacement of the switch are varied for the faulty cases as expected. But, the exact parameter of degradation is not recognised from the time domain plots.

$$res_k = y_k - y_{kh} \tag{4}$$

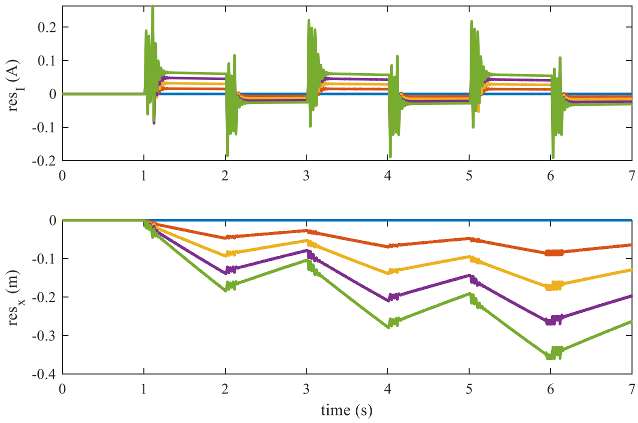

Fig. 5 Input Voltage and Residuals (motor current and displacement) under the different health conditions

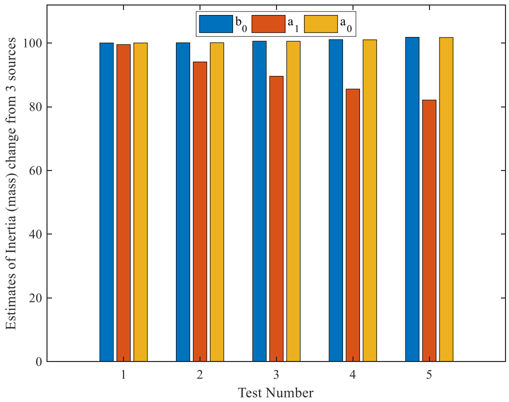

Fig. 6 Estimated parameters over five tests when friction changes.

Fig. 6 shows the plot when the friction of the switch panel is changed using Simpack over five tests. The estimated coefficient a_1 is shown to detect the change which directly relates the equivalent viscous coefficient K_f of the switch system.

III. Experimental Results

An electromechanical actuator is designed which consists of an electric motor, gearbox and a ball-screw. The actuator before installing into the switch system is validated first. The validation results show that the model of the actuator matches closely with the design model.

The actuator is now installed in the switch system in the laboratory in BCRRE, the University of Birmingham and initial data collection with a healthy switch system is being carried out. Fig. 7 shows the displacement and current data available from the switch system.

The validation of the model with the experimental data is completed through this project. In the next part of the research, different fault scenarios such as a change in the frictional element and mass of the system will be generated in the laboratory environment. The data of these fault scenarios will be tested with the continuous time parameter estimation technique as discussed to check its effectiveness.

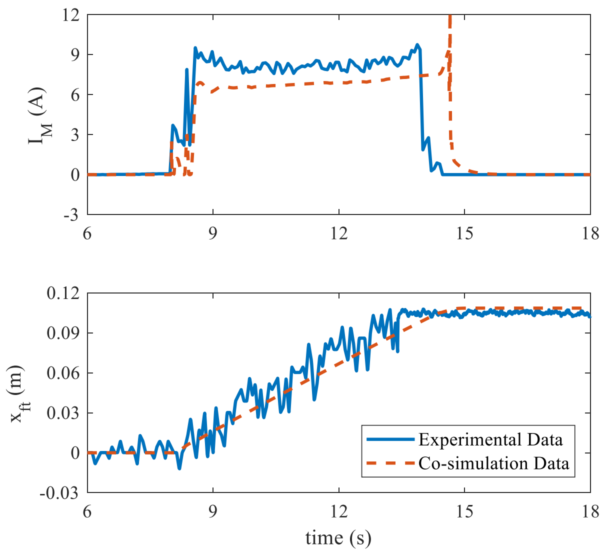

Fig. 7 Validation of experimental data with the co-simulation for single switching action

IV. Conclusions

The study focuses on the use of iterative Simplified Refined Instrumental Variable (SRIV) method for Continuous-time systems to estimate the parameters of a switch system while in operation. The multibody simulation (MBS) model of High Performance Switch System (HPSS) is used to test the condition monitoring technique and the continuous time parameter estimation method is shown to predict the parameter degradation of the switch system. Different fault/unhealthy case scenarios are tested with the simulation model along with the developed condition monitoring technique and checked for its functionality. The contribution of this study is to show the effectiveness of the continuous-time parameter estimation technique and a validation of experimental results. This is a foundation study and it is planned that the technique will be used with current and displacement sensor data collected from the working track switch system. The expected impact of this method will lead to reducing the number of the scheduled maintenance required for the switch system which in turn reduces the maintenance cost and increase the capacity of trains in the network.

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