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A real-time predictive maintenance system for machine systems

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Abstract

This paper describes a novel real-time predictive maintenance system for machine systems based upon a neural network approach. The ability of a neural network to learn non-linear mapping functions has been used for the prediction of machine system parameters using the motion current signature. This approach avoids the need for costly measurement of system parameters. Unlike many neural network based condition monitoring systems, this approach is validated in an off-line proof of concept procedure, using data from an experimental test rig providing conditions typical of those used on production machines. The experiment aims to classify five distinct motor loads using the motion current signature, irrespective of changing tuning parameters. Comparison of the predicted and actual loads shows good agreement. Generation of data covering all anticipated machine states for neural network training, using a production machine, is impractical, and the use of simulated data, generated by an experimentally validated simulation model, is effective. This paper demonstrates the underlying structure of the developed simulation model.

Keywords: Neural network; Motion current signature; Machine parameter; Predictive maintenance

1. Introduction

Much emphasis has been given to the research and development of high speed machine systems possessing high levels of programmability and reconfigurability. Motion cycle demands in such machines are high; motors and drives are required to perform under demanding conditions, hence the need for a preventive maintenance system. Modern machines typically use some form of direct current (DC) motor and the process described is based upon such motors.

The DC motor is one of the first machines devised to convert electrical power into mechanical power. Recent improvements in DC machines, and specifically the emergence of the brushless motor have lead to its wide usage due to its high torque and small size when compared to induction motors.

The need for new high-performance motors, with highly sophisticated capabilities, has produced an abundance of new types and sizes of DC motor. Nowadays, DC motors are widely used in many machine applications; with this there is a need for high reliability supported by an effective maintenance system. Recent studies have demonstrated that the technique of predictive maintenance approach can ensure high reliability and performance [1,5–7,10,16,20].

This paper introduces an effective, real-time, predictive maintenance system based on the motion current signature. The aim of the proposed system is to localize and detect abnormal electrical conditions in order to predict mechanical abnormalities that indicate, or may lead to the failure of the motor [12,13].

Conventional techniques require an accurate mathematical model in order to predict the dynamic behavior in response to a command input [2–4,8,9,11,15]. This requires that system parameters such as load, backlash and torque are accurately known. Tracking of the system parameter changes during the operation

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Nomenclature

K_p	position proportional gain
K_i	position integral gain
K_d	position differential gain
P_{cmd}	position command
P_A	actual position
P_{err}	position error (current sample)
P_{errp}	position error (previous sample)
P_{int}	position error integral
P_{diff}	position error differential
V_{ff}	shaft velocity
V_{gain}	velocity proportional gain
I_{gain}	velocity integral gain
K_{ffv}	velocity feed-forward gain
K_{ffa}	acceleration feed-forward gain
V_{cmd}	velocity command
V_A	actual velocity
V_{err}	velocity error (current sample)
V_{errp}	velocity error (previous sample)
V_{errint}	velocity error integral
$V_{errdiff}$	velocity error differential
I_{cmd}	current command
T_{cmd}	torque command
J_L	load inertia
G_T	external torque
F_T	friction torque
J_M	motor inertia
K_t	motor torque constant
F_{Tm}	motor friction torque
T_s	time slice

necessitates costly instrumentation, which is difficult to justify on a production machine system. The approach presented here allows deviations from the normal dynamic behavior to be predicted accurately based upon the interpretation of the motor current characteristic. The system uses a neural network which learns the non-linear mapping function between system parameters and motion current signature and avoids the need for costly measurement of system parameters. The neural network has been shown to be an effective technique for performing motor fault detection [14,17–19]. Successful implementation of neural networks for motor fault detection and diagnosis, up to an accuracy of more than 90%, has been achieved [18].

A fundamental requirement for the successful implementation of a neural network is the availability of relevant, information-rich training data. This application requires machine parameters to be varied to cover all anticipated machine conditions; which ensures that any parameter variation can be interpolated [21–23]. While an ideal solution would be to utilize training data from a real production system, this is impractical for a number of reasons:

1. a large number of sensors would be required to collect data relevant to all machine parameters;
2. machine faults are rare and unlikely to occur;
3. it is impractical to scan the entire range of machine operations.

This motivates an alternative approach for developing a system which generates the training data using simulation models. Simulation modelling is a valuable alternative provided that the model is fully validated against a real production machine [13]. The model can be used to generate the training data covering all anticipated machine conditions. The simulation model developed for this system is the result of a joint University and Rockwell Automation research programme. Initially, the primary objective was to develop a tool that would be used to optimize the size and selection configuration for motors, drives and systems [24–33]. Enhancements were added to provide a