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Fault diagnosis of vacuum cleaner motors

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Abstract

In-depth and automatic quality end-tests in modern manufacturing represent an important means for the assurance of top-quality and flawless products. Tough competition on the market of vacuum cleaner motors is increasing the need for fast, reliable and objective quality assessment of every single unit at the end of the assembly cycle. As a step towards meeting these objectives, a prototype version of the diagnostic system for quality tests of vacuum cleaner motors has been designed. The core of the system contains four modules for features extraction that employ, respectively: analysis of commutation, vibration analysis, sound analysis and check of parity relations. The symptoms resulting therefrom are processed by an approximate reasoning module, which utilises the technique referred to as the transferable belief model (TBM). The comprehensive diagnostic procedure is able to clearly distinguish a faulty motor from a non-faulty one and to infer about the tentative fault location. Main contributions of the paper refer to the novel feature extraction procedures, which provide a reliable estimate of the motor's condition. The system performance has been surveyed on a set of about 100 motors subjected to a detailed experimental study. An excerpt is also presented, reflecting the key properties of the diagnostic system performance, such as precision, accuracy, robustness and reliability.

Keywords: Universal motor; Fault diagnosis; Vibration; Sound analysis; Approximate reasoning

1. Introduction

The manufacturers of vacuum cleaner motors tend to purchase (almost) 100% fault-free devices at the lowest prices. This demands a thorough and efficient process of quality assurance during the manufacturing cycle.

This paper addresses a family of vacuum cleaner motors produced by the company Domel, which is one of the leading European manufacturers. The process of quality assurance in Domel is organised across three levels. First, several standard automated tests are performed on the most critical components already during assembly (e.g. rotor balance, high-voltage test, etc.). As a matter of fact, those tests are able to reveal defects only at the component level. In other words, some errors occurring during the assembly process might become visible not earlier than on the end product. That is why a thorough test of the condition of the end product is so important. The second level of quality assurance applies in-depth scrutiny of a statistical sample of motors taken from each shift. The third level comprises the lifetime tests of a sample of motors from the finished series. This kind of quality assurance is rather laborious and costly as well. Therefore, it is hoped that costs could be reduced by employing thorough automated end-tests, able not only to reveal defective motors but also to isolate the root cause. Thus the operators will have the opportunity to take early corrective actions on the assembly line.

Fault diagnosis of rotating machines, in general, has been well addressed in several papers (cf. Edwards, Lees, & Friswell, 1998; Randall, 2002; Nandi & Toliyat, 1999, for overviews). In the particular case of universal motors, various ideas have been exploited. For example, Gühmann and Filbert (1991) reveal various electrical and mechanical defects solely from current analysis. Vetter, Weber, and Grossehelweg (1994), cf. also web page of company Schenck (2003), focus on the end-test

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of vacuum cleaner motors by combining vibration analysis and a mathematical model of the motor in order to check motor quality at the end of the production line. Use of a mathematical model as a feature generator for a similar problem is also reported by Albas, Durakbasa, and Eroglu (2000). The system delivered by company Vogelsang and Benning (2003) entails several checks including vibrations and sparking. The underlying systems are claimed to be applicable to a large family of electrical motors. However, neither detailed reports on the achievable diagnostic sensitivity and precision, nor what is the feasibility to handle unanticipated faults are provided.

The key objective of the present work is to enhance the performance of automatic end-control of universal motors by improving its reliability, diagnostic precision and particularly sensitivity with respect to faults. The underlying paper introduces a novel approach to quality assessment of vacuum cleaner motors by making use of a comprehensive set of features derived from the analysis of commutation, vibration analysis, sound analysis and model-based parity relations. Indeed, the quality of a vacuum cleaner motor can be deteriorated by a number of factors, such as missing contacts, poor balance of rotating parts (vibrations), improperly mounted bearing, undesired sounds due to impacts, etc. These defects are mostly due to errors in assembly procedures. Hence, the goal is to reveal them accurately by a high-quality end-test in order to open the way towards delivery of 100% fault-free motors to the customers. By using a set of elaborated detection algorithms, the diagnostic sensitivity of the underlying system is hoped to have been improved compared to the sensitivity of the systems known so far.

The purpose of the paper is to describe a prototype design of a diagnostic system for quality end-test of vacuum cleaner motors. The core of the system consists of four modules for feature extraction. The generated features are further processed by a module for fault isolation based on approximate reasoning. The paper is organised as follows. The diagnostic system structure and the underlying measurement set-up are introduced in Section 2. Feature extraction modules are summarised in Sections 3, 4, 5 and 6, respectively. Section 7 reviews the basics of the fault isolation strategy. In Section 8, the evaluation of the diagnostic modules is presented.

2. Diagnostic system structure

2.1. Motor description

The vacuum cleaner motor addressed in this paper is shown in Fig. 1. The fan impeller with nine shovels mounted on the motor's shaft generates airflow through the hole in the cover. The diffuser directs the airflow through the aperture between stator and rotor in order to cool the motor. The nominal rotational speed of those motors f_0 is about 550 Hz.

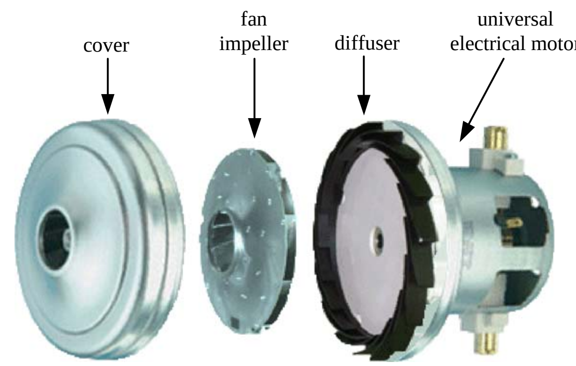

Fig. 1. Components of the vacuum cleaner motor.

2.2. Sensors

Six different physical quantities are acquired during the short test runs, in particular: supplied voltage, current, brushes voltage, vibration signal, sound and rotational speed. Vibrations are sensed by a piezoelectric sensor mounted on the housing in order to sense acceleration. Sound is acquired by means of a microphone mounted in an anechoic chamber. Finally, rotational speed is measured with an infrared sensor, which detects a black mark on the motor's shaft.[1]

2.3. Hardware

The hardware platform of the system consists of an AC power supply, a signal conditioning unit and a personal computer with data acquisition card NI 6035E. This card is able to operate at 200 kS/s (kilo samples per second). During the test, a motor is placed in the anechoic chamber and run along a pre-specified velocity profile controlled by a control unit (see Fig. 2).

2.4. Software

Data acquisition is realised in LabVIEW (National Instruments). The architecture of the algorithmic part of the system (Fig. 3) consists of four feature extraction modules that operate on data taken during motor operation. These modules blend methods of signal processing and parity relations. Finally, a reasoning module isolates potential defects and calculates the belief measures associated with the faults.

[1] Analysis shows that the sensor for rotational speed could be replaced by an estimator relying on cepstrum analysis of the sound signal.