Detection of Wheel Loss in Buses and Heavy Goods Vehicles

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An MEng 4th Year Project with the School of Electrical and Electronic Engineering

Introduction

Information from the UK Vehicle Inspectorate shows that, between 1982 and 1994, there were 323 reported wheel loss incidents. It has been suggested that if all events were reported this number would exceed 3000, resulting in about 10 fatalities a year.

Wheel loss incidents are particularly important in public service vehicles, such as buses and coaches, where loss of life can be greater in the event of an accident. A number of mechanical solutions to this problem exist, such as visual warning indicators, but these rely on human interaction for fault awareness. It is also known that in a wheel loss event, it is possible for all wheel nuts to detach within a very short time-frame. As this is a factor that wheel-mounted visual warning systems cannot cope with, the speed of detection is of utmost importance.

Aims

This project researched, designed and produced a prototype electronic system to detect the early warning signs of wheel loosening, and to report such events to the vehicle's driver in the shortest possible time. This will allow the driver to bring the vehicle to a safe and controlled stop. The initial aim was for the system to be capable of being retrofitted onto most vehicles without much, if any modification. Development difficulties have meant that the present system requires modification to the wheel assembly.

Objectives

- To create a sensor mechanism capable of detecting the onset of wheel loss
- To create a scalable detection system for multi-axle vehicles
- To provide both audible and visual indications
- To include a self-sufficient power source
- To create a wheel-to-chassis wireless communication link
- To develop a computer application to display calibration and diagnostic information

Wheel Mounted Subsystem

The wheel mounted system comprises sub-systems for on-wheel power generation, regulation and storage, force sensing for nut-loosening detection and data transmission.

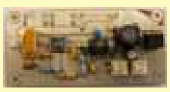
Power Generation and Storage Sub-systems

- Power generation is achieved by using a permanent magnet DC motor acting as a generator
- The motor body (stator) is attached to the half-shaft of the bus wheel axle
- The rotor of the motor is held in place gravitationally by a suspended mass which is attached to the gearbox shaft
- Power storage is essential as insufficient power is generated when the vehicle is commuting at low speeds or at a standstill
- The battery management circuit (Maxim MAX173) handles the power storage using 4 NiMH batteries with fast charging and trickle charging

Mounting Assembly

Power Regulation

- Wide input voltage range (0 V at standstill to 60 V at full speed) from generator
- A stable voltage is essential for the sensing and communication electronic circuits
- Energy storage and 'buck/boost' voltage regulation necessary
- Currently developed system can down-regulate to 3 V from an input of 4 to 60 V



Regulator Circuit

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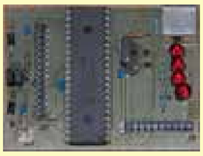
Chassis-mounted Wireless Receiver

Two boards form the chassis-mounted wireless receiver sub-system, one is based on the Texas Instruments TRF6903 ISM band transceiver and receives signals from the wheel-mounted sub-system, and the other, based on a Microchip PIC18LF4520 microcontroller, decodes the incoming data stream and performs CRC-based error checking before sending the sensor and status data to the Driver's In Cabin Unit.

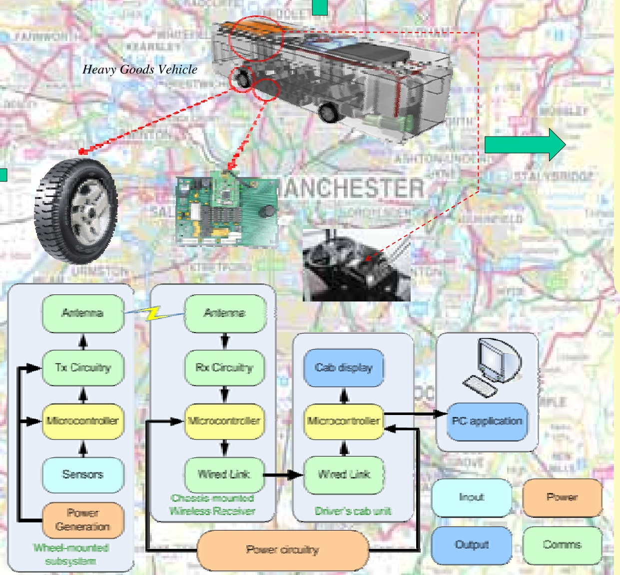


Wireless Receiver Microcontroller Board

Wireless Receiver Board

Wireless Data format

Operating in the 433 MHz ISM Band: with a transmit power of -12 dBm
Frequency Shift Keying (FSK) modulation: Using two frequencies centred about a frequency of approximately 433 MHz, frequency shift keying modulates binary data. A zero is represented by the lower frequency, and a one by the higher.
Manchester Coding: A coding scheme that enables the wireless link to be synchronised by introducing at least one zero-crossing (change in frequency) per data bit transmitted; performed at the cost of halving the total data throughput.
Data rate of 2.4 kbits per second: A 4.8 kHz reference clock is used for synchronising data transmission; with the use of Manchester coding the total data throughput is halved to 2.4 kbits per second.
8-bit CRC Checking: A simple to implement, computationally cheap, Cyclic Redundancy Checking (CRC) scheme for detecting data errors on the link.



System Overview

Wheel Mounted Subsystem (cont.)

Sensors

- Numerous mechanical solutions for detection of wheel nut loosening - Check Point® device and SmartBolts® - require visual identification and prone to tampering

The team have developed

- A customised load cell for detecting the loss of force loss between the wheel studs and the wheel rim
- A steel spring and a temperature compensated strain gauge; applied force changes the resistance of the strain gauge element
- A high precision (24-bit) Analogue to Digital Converter (ADC) provides a digital representation of the measured forces
- Calibration allows a digital 'cut-off' to be programmed

Position of sensors

Transmitter

Data is transmitted to the chassis-based receiver by a Texas Instrument TRF4903 ISM band RF transmitter operating at a frequency of 433 MHz.

Driver's In Cabin Unit (INCU)

- Central controller of the wheel loss detection system
- Collects information from the sensors mounted on each wheel
- Alerts the driver in the event of any potential wheel problems
- Stores sensor data in non-volatile memory - a black box data recorder for maintenance engineers
- Provides data for an external, PC-based diagnostics terminal
- **Diagnostic mode:** allows memory to be probed and the system to be reset
- **Running mode:** sensor information is passed through the interface for visualisation on a computer terminal
- Wired transmission system for communication to chassis-mounted receivers
  - Employing differential signaling to overcome noisy electrical environment
  - Uses point-to-point links for robustness

In Cab Unit

PC Application

The PC Application provides a Graphical User Interface (GUI) for the vehicle mounted electronic system and thereby simplifies diagnostic operations. It is to be used by mechanics during scheduled maintenance operations.

The diagnostics program is run on a computer connected to the INCU via an RS-232 based serial link. The INCU is programmed to provide diagnostics output to a terminal using 8-bit ASCII character encoding, with no flow control.

Diagnostic Program

The application is implemented as a Windows dialog box. The lower section contains a terminal 'dump' of the raw data received. In addition to this buttons are provided to send requests back to the INCU.

Each wheel is represented by a small child window, which shows the number and status of the wheel and interpretation of any errors detected.

Test Rig

Test Rig Side/Back View

Test Rig Front View

- Comprised of the rear double driving wheels of a rear-engine bus, and included two wheels rims, a brake drum and brake, wheel hub, drive axle and differential
- Constructed to allow testing of the sensing, power generation and communication sub-systems under typical rotational conditions and consequent forces
- Designed for:
  - Variable speed up to 500 RPM, using a 1.5 kW induction motor and 1-phase to 3-phase power electronic drive
  - Easy transportation – Vertical A-frames supported by horizontal struts; may be disassembled into smaller components
  - Safe operation, with emergency stop, combined steel mesh and polycarbonate guards and axial restraining pins for wheels

Conclusions

- Sustainable power generation, capable of producing > 10 V under load
- Wireless link from rotating wheel to fixed chassis receiver, which copes with the Doppler Effect and provides robust communication
- Stable differential wired communication
- Visual and audible error warning to driver with data logging
- System status visible via PC application – the produced voltage and system errors are clearly shown
- Sensor mechanism conditioning and detection system
  - Fine grained digital results – discerning varying levels of torque
  - Robust materials for sensor element need investigation