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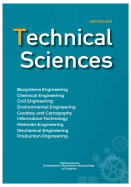

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CONCEPT OF A SYSTEM FOR REMOTE VIBRATION MEASUREMENT IN ELECTRIC VEHICLES DRIVEN BY ROTARING BODY MOTORS

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Abstract

The article proposes a vibration measurement system for electric vehicles powered by motors with rotating housing. The motors were designed and patented by the author. The presented solution is characterized by low cost, high reliability and minimal power consumption. Block diagrams of the designed system were presented and described in detail.

Introduction

Mechanical vibration measurements are an important part of the diagnostic process in modern machines and devices. Vibration damping not only minimizes discomfort in the working environment, but also considerably increases a machine's service life. Therefore, solutions that effectively minimize vibration are a vital concern for all operators of mechanical devices.

This article proposes a remote (wireless) vibration measurement system for electrical vehicles. However, the presented solution can be also applied to diagnose

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other vibrating elements in mechanical equipment. Description of patented motor can be found in SYROKA (2019) and SYROKA, SKŁODOWSKI (2021).

Vibration in electric vehicles

All mechanical devices with moving elements generate mechanical vibration and are sensitive to external sources of vibration. Vibration is a particular concern in electric motors with rotating housing. Vibration should be effectively controlled and attenuated to improve operating comfort, decrease noise levels in the machine's immediate environment, prolong the machine's service life and improve performance. Vibration is propagated to other parts of a vehicle, which not only decreases the user's comfort, but also compromises safe vehicle operation.

Vibration generated by an electric motor can be transmitted to other elements of a vehicle. Most vehicle components are elastic bodies where mechanical waves are easily propagated. However, every elastic body vibrates at a specific frequency which is influenced by its geometric characteristics and mass distribution. Magnetic resonance occurs when the frequency of forced vibration (transmitted by other elastic bodies) is equal to a component's own characteristic vibration. Due to the rigidity of structural materials and the operating principles of an electric motor, vibration cannot be completely eliminated, but it can be substantially reduced by applying damping elements (rubber pads), screens, cushions or systems that stabilize vibrating components. These solutions are introduced to minimize the transmission of vibrations not only by elastic bodies, but also by the surrounding air.

Advanced vibration control solutions require not only precise mathematical models of vibrating systems and dedicated structural materials, but also reliable vibration measurement methods. Therefore, the aim of this study was to design a simple system for remote measurement of selected vibration parameters in an electric motor and other moving parts in an electric vehicle.

Design of a vibration measurement system

The proposed system was designed with the use of TTL and CMOS integrated circuits without programmable logic devices or microcontrollers. This solution was selected because it speeds up system activation, does not require dedicated software and minimizes power consumption.

The system features a remote vibration sensor composed of five main modules: vibration sensor, IR transmitter, IR receiver, frequency counter, and voltmeter. The system is presented in a block diagram in Figure 1.

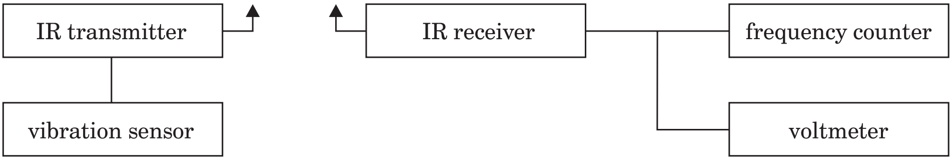

Fig. 1. Block diagram of a remote vibration measurement system

The two last modules are optional and can be replaced with mass-produced instruments that measure electrical properties, such as standard multimeters. The designed structure is not only simple, but also cheap because it relies on widely accessible parts and does not feature specialist components such as accelerometers that require additional stabilizers and power adaptors.

The sensor is a modified version of a vibration monitoring system that has been adapted for continuous measurement of mechanical vibrations. The active element is a standard piezoceramic transducer that is attached to a metal disc with a diameter of around 20 mm. When the disc is deformed, the transducer converts mechanical vibration energy to electrical energy, and charged particles are accumulated on the walls. One side of the disc is fixed to the surface of the examined component, and the other side is subjected to a small load. The vibration produced by the analyzed component leads to changes in the thickness of the piezoelectric disc due to the inertia of the applied load, which changes the electric signal and generates weak electric pulses.

The generated pulses are weak and have to be amplified to control the IR transmitter. The sensor can have any supply voltage (provided that it is sufficient to control the amplifier), but higher voltage increases power consumption and shortens the sensor's operating time. The IR transmitter was built around the 555 timer integrated circuit which generates square waves with a steady frequency. The control signal temporarily blocks and unblocks the generator; therefore, the square wave is keyed at the output. The frequency of the modulated signal corresponds to the frequency of the signal received from the piezoelectric disc. The operating point of the amplifier carrying the signal from the piezoelectric disc can be modified or additional conditioning modules can be applied to generate a modulated signal that carries information about the frequency as well as the amplitude of vibrations.

The IR receiver comprises a TFMS 5,360 circuit with a receiver photodiode, a preamplifier, automatic amplification control, a very steep band-pass filter, and a sensing system. The receiver is not sensitive to interference in the visible light spectrum or even the infrared spectrum with a different frequency. It transmits signals with a frequency of 0-800 Hz with modulating signal frequency of 36 kHz.

The signal received by the IR receiver has to be transformed to an unmodulated square wave. This can be accomplished with the use of a single low-pass filter with capacitance modulation and frequency discrimination.

The filtered signal reaches the frequency counter and, if it passes through a frequency-to-voltage converter, it is fed to a voltmeter which measures the effective value of the wave. As previously mentioned, both meters can be integrated into the system or used independently.

Block diagrams of the vibration measurement system

A block diagram of the vibration sensor with a piezoelectric disc is presented in Figure 2. When the supply voltage of the UCC device is 5 V, power consumption is minimal in stand-by mode, but it can increase substantially during operation.

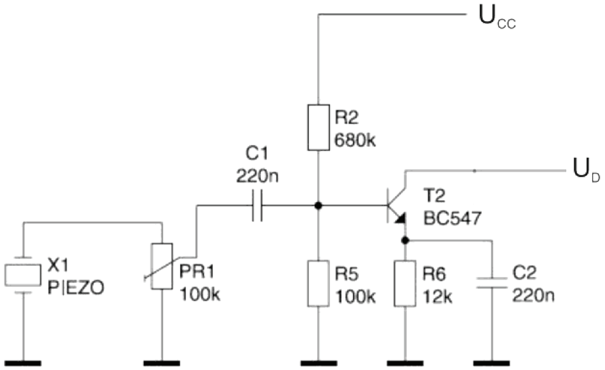

Fig. 2. Block diagram of a vibration sensor with a piezoelectric disc

A block diagram of the IR transmitter is presented in Figure 3. The transmission system comprises four IR diodes that are connected in series and controlled by the 555 timer IC via a simple MOSFET amplifier. The IR transmitter and the vibration sensor should be located on the same board.

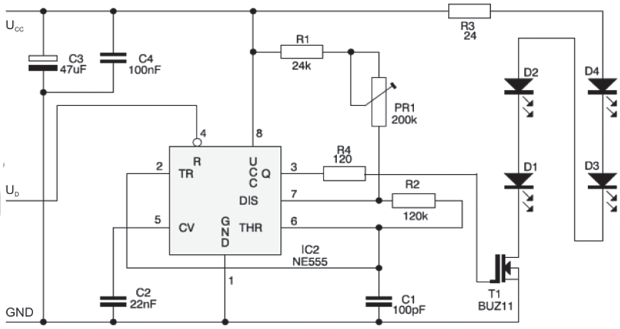

Fig. 3. Block diagram of the IR transmitter

A block diagram of the modulated IR signal receiver is presented in Figure 4. The receiver was built around a TFMS 5,360 circuit. The received signal is directed to a voltage converter composed of a BC548 transistor that amplifies the signal and inverts the signal phase because the TFMS circuit originally yields the inverse of the received signal. The IR sensor should have a stable supply voltage of +5 V, which can be achieved with the use of the LM7805 voltage regulator. The entire system should have a supply voltage of 7-10 V with minor pulsation.

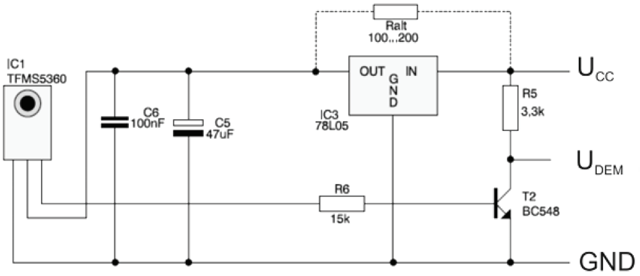

Fig. 4. Block diagram of the IR receiver

The frequency counter is presented in Figure 5. The frequency counter comprises CMOS logic circuits which are characterized by a wider range of logic signal voltage levels, lower power consumption and higher operating frequency than TTL circuits.

The frequency counter should have a supply voltage of minimum 7 V because supply voltage is subsequently stabilized in the LM7805 voltage regulator. The application of two independent voltage regulators on the same board can be problematic, but this solution offers more effective voltage stabilization, improves IR signal transmission and reduces the amount of heat radiated by each voltage regulator. The proposed solution also eliminates the need for heat sink radiators that are difficult to manage. The only disadvantage of this solution is that supply voltage is relatively high. Therefore, if the base module is to be operated as a portable device, 9 V 6F22 batteries may be insufficient, and rechargeable batteries should be considered.

The measured signal is transmitted to the UDEM input and a signal conditioning gate with a Schmitt trigger. A gating signal composed of a square wave with 0.5 Hz frequency and 50% duty cycle is fed to the second input in the Schmitt trigger. The signal opens the trigger, and the pulses enter the counter. The entire measurement cycle lasts 2 s.

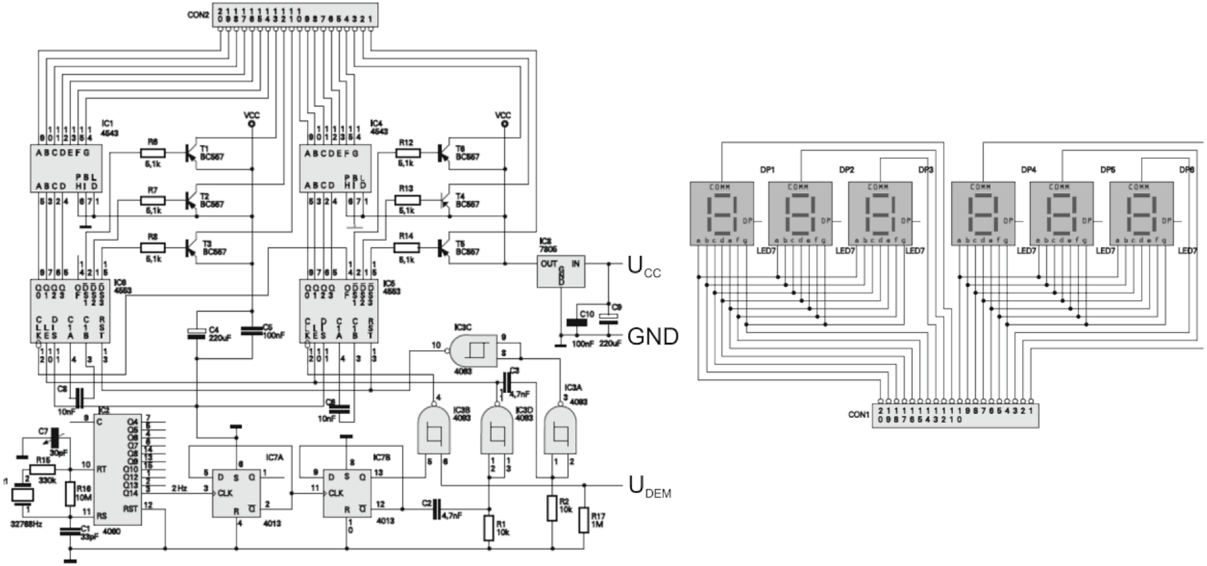

Fig. 5. Circuit diagram of the frequency counter comprising CMOS integrated circuits and connections with the 7-segment display module

Operation of system modules

The general operating principles of individual modules were described in the previous sections, and the operation of the entire system is presented in this section.

The piezoelectric disc has to be correctly mounted. A cylindrical sleeve was glued to one side of the disc. The sleeve should have a somewhat smaller diameter than the metal plate which introduces the required inertia and joins the disc with the board. A short support was attached to the second electrode for the purpose of mounting the sensor to the vibrating object. The entire sensor unit with the IR transmitter module has to be sufficiently rigid and precisely balanced to prevent external torque other than the torque of the vibrating object from acting on the piezoelectric disc. Therefore, the sensor should be mounted in a vertical position. The piezoelectric disc is sensitive to high temperature, and adequate cooling should also be provided.

The system is controlled by modifying the operating point of the amplifying transistor. The operating point should be set near the maximum voltage of the amplified signal to increase sensitivity to changes in the amplitude of voltage generated by the piezoelectric disc. However, excessive voltage should not be applied to ensure the correct operation of successive elements in the system. The operating point is modified by changing the value of resistor R2, and sensitivity is controlled with a PR1 potentiometer. A simple lower-pass filter can be placed between the piezoelectric disc and transistor T2 to eliminate the DC component which is generated when the piezoelectric disc is subjected to static load.

As previously mentioned, the multivibrator keying signal in the IR transmitter path blocks or unblocks the generator. An active generator is in a high state, and it ceases to operate in a low state. The IR transmitter is controlled by modifying the frequency of the carrier wave with a PR1 potentiometer. Wave frequency should be set at 36 kHz with the use of a frequency counter or an oscilloscope, or by selecting the optimal transmission parameters when the transmitter and the receiver are separated by a certain distance. Interestingly, the receiver-transmitter unit also operates when the beam is reflected, for example from a shiny surface; therefore, direct visibility between the transmitter and the receiver is not required.

The frequency counter consists of a cascade of six decimal counters, and frequency is measured within a range of 0 to 999,999 Hz. The counters are not synchronous, and they have to be coupled to displays with BCD to 7-segment display decoders. These counters count the pulses entering Schmitt trigger gates which are opened for 1 s by square wave pulses produced by a crystal generator. The generator was built around a standard 4060 IC with an external 32,768 Hz crystal oscillator, a built-in stabilized generator and a frequency divider that counts to 2^{14}. Therefore, the output signal has a frequency of 2 Hz. Schmitt triggers of IC3 should have a frequency of 0.5 Hz; therefore, the frequency of the output signal has to be divided by 4. Two D-type flip-flops (4013 IC6, IC7) were used for this purpose. When the enable input is in a high state, the remaining gates are blocked and the measured signal can pass. When the enable input is in a low state, counter data are copied to display buffers. Gate opening time is exactly 1 s; therefore, the number of counted pulses is equal to the frequency of the measured signal. Buffer outputs are reset after counter data have been copied, and the entire system is ready for the next measurement cycle. The purpose of the calibration process is to set the frequency of the crystal oscillator to 32,768 Hz, which can be achieved with the use of an oscilloscope or a calibrated frequency counter.

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