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Inductance of a double-body compression spring as a favorable seat occupancy sensor

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Abstract

In this paper a method for dimensioning of inductive spring sensors is shown. This is done using an example of seat occupancy detection sensor of the automotive industry. It is in this case deals with the calculation of the individual components of the spring sensor. Thereby the crucial part for this is the calculation of the inductance of the spring sensor, because the components of the signal processing must be designed for them. Furthermore, it is shown how the example of the seat occupancy detection sensor, the analogue measurement signal is generated and can be calculated. The results of the development of the seat occupancy detection sensor are presented. This method can be used to design any other inductive spring sensors. This offers the advantage that a cost-effective development of spring sensors is possible, because they can be dimensioned theoretical first.

Key words: Spring sensor, force sensor, displacement sensor, sensors construction, inductive sensor

Introduction

In many technical applications because of their mechanical properties springs are used. Because of the economic demands on technical applications, it is desirable that springs in addition to their mechanical properties can also be used as sensors. Spring sensors got a simple construction and are a favorable alternative to other displacement- / force-sensors. One possible application is a displacement sensor. For this purpose the geometric properties of a spring can be utilized. The geometric shape of a spring is very similar to a coil. Therefore, it is obvious that one can use the inductance of this spring to measure the deflection of the spring. In this paper the calculations for the design of a double-body compression spring sensors are presented by the example of seat occupancy detection sensor for motor vehicle seats [1].

Mechanical structure and requirements

In the automotive industry requirements are placed for sensors. By the one hand, such sensors have to be very robust. On the other hand it is required that these sensors are very inexpensive. These requirements are met by the simple structure of the double-body compression spring sensor. Since small amount of space is available at the mounting location under the car seat, it is also required for use of the double-body compression spring sensor as seat sensor that this sensor has a maximum deflection of two millimetres. In addition, the sensor should not exceed a maximum height of two centimetres. The key element in this sensor is a double-body compression spring. The spring coils are carried out similarly as in an electrical coil with two layers. This has the advantage, that the spring can be contacted on the lower side. Thus, no additional electrical connection of the one end of the spring to the other end of the spring is necessary. To achieve the required mechanical properties, a double-body compression spring is used with two times 5.5 turns. The inductance, which is used as the measured size is very small due to the small number of turns of the double-body compression spring. It follows that the impedance of the spring is also very small. For this reason, a non-contact variation was chosen to measure the inductance of the spring. This is done using a receiver coil. The double-body compression spring is electrically short-circuited at their ends, whereby the principle of a secondary side short-circuited transformer can be used. The double-body compression spring and the receiver coil for a seat occupancy detection sensor are shown in figure 1.

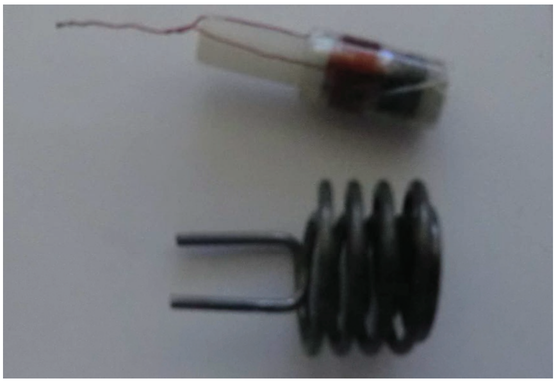

Fig. 1. Receiver coil (above), double-body compression spring (below)

The double-body compression spring in figure 1 consists of spring steel. The receiver coil in figure 1 is composed of a bobbin and a copper wire coil which consists of 6 layers with 21 turns. The double-body compression spring and the receiver coil are located in a chasing having a cover which is used as a pressure bearing surface (Fig. 2).

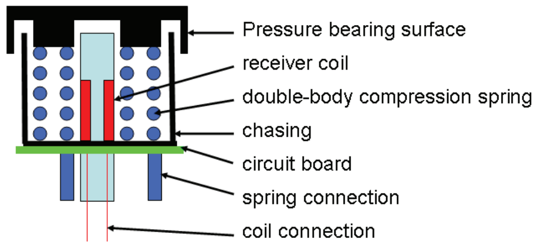

Fig. 2. Structure of spring sensor

The double-body compression spring is arranged that the receiver coil is enclosed by the double-body compression spring. The connections of the double-body compression spring and the lower end of the coil bobbin of the receiver coil are led out through the chasing base. The chasing of the spring sensor serves as a touch guard and as a stabilizer preventing a snap of spring. The lid of the chasing is used as defined pressure bearing surface. On the bottom side of the sensor chasing a circuit board with the electronics is fixed for signal processing. As a result, the connections of the double-body compression spring and the receiver coil can be contacted directly on the circuit board for signal processing. From the circuit board, the processed measurement signal can be transmitted to a digital processing unit.

Modeling of the sensor spring

The electrical properties of the double-body compression spring and the receiver coil are calculated for the arrangement of the analogue signal processing. The inductance of the spring and the receiver coil and the mutual inductance between the spring and the receiver coil can be calculated with (1).

$$M_{12} = \frac{\mu}{4 \cdot \pi} \cdot \oint_{C_1} \oint_{C_2} \frac{\overrightarrow{ds_1} \cdot \overrightarrow{ds_2}}{\left\| \overrightarrow{r_1} - \overrightarrow{r_2} \right\|} \qquad (1)$$

For this purpose, a model of the spring and of the receiver coil is created firstly. The conductor centreline of the spring and the receiver coil are included in this model. The conductor centreline of the spring is the curve C_1 and the conductor means contour of the receiver coil is defined as the curve C_2 for calculating the mutual inductance with (1). The centreline of the double-body compression spring and the receiver coil is used as the curve C_1 and the outer edge of the contour of the double-body compression spring and the receiver coil is used as the curve C_2 for calculating the self-inductance of the double-body compression spring and the receiver coil with (1). The models of the centreline are shown in figure 3.

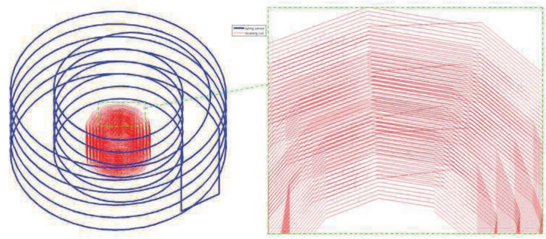

Fig. 3. Double-body compression spring (blue) receiver coil (red)

The blue outline in figure 3 shows the electrically short-circuited double-body compression spring. The red outline shows the receiver coil. In figure 3 it can be seen that the conductor mean contours are discretized in line elements. This is because that (1) is not closed releasable. In [2] and [3] solutions of (1) are presented for straight line elements. The solution of [3] is used for the calculation of the inductors, because this solution makes use of a simpler geometric model. The result of the inductance of the receiver coil is 18.7 µH. The inductance of the electrically short-circuited double-body compression spring as well as the mutual inductance between the electrically short-circuited double-body compression spring and the receiver coil dependents of the deflection of the spring. For this reason, the inductance of the spring and the mutual inductance is determined with (1) for a deflection between 0 and 2 millimetres (Fig. 4).

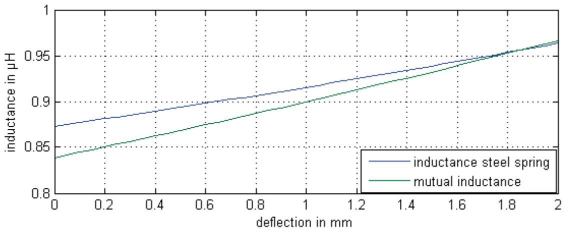

Fig. 4. Inductance double-body compression spring (blue) / mutual inductance (green)

From Figure 4 it is clear that the inductance of the double-body compression spring and the mutual inductance between double-body compression spring and receiver coil rise for a deflection of the spring. The change in the mutual inductance as a function of the deflection is greater than the change in the inductance of the spring. At the next step, the electric resistance of the double-body compression spring and the receiver coil are determined. This can be determined by (2).

$$R = \frac{l}{\kappa \cdot A} \qquad (2)$$

The length of the unwound copper wire is used for the length l to calculate the electric resistance of the receiver coil with (2). The length of the unwound spring steel wire is used to calculate the electric resistance of the double-body compression spring. The electrical conductivities of each material are used for the conductivity κ. The sectional area A is the spring wire sectional area and the copper wire sectional area. This results in an ohmic resistance of the receiver coil of 0.58 Ω. The ohmic resistance of the double-body compression spring is 96 m Ω. The electrical properties of the double-body compression spring and the receiver coil are determined. These can be represented in an equivalent circuit with concentrated elements. Figure 5 shows the equivalent circuit of the short-circuited double-body compression spring and the receiver coil.

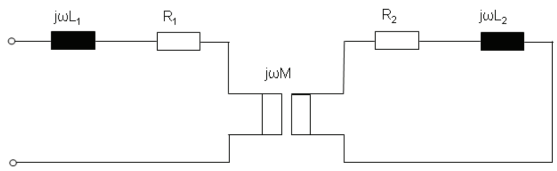

Fig. 5. Equivalent circuit of the short-circuited double helix spring and the receiver coil

The impedance of the equivalent circuit calculated. The resulting impedance Z can be determined by (3).

$$\underline{Z} = R_1 + \frac{\omega^2 M^2 R_2}{R_2^{\,2} + \omega^2 L_2^{\,2}} + j\left(\omega L_1 - \frac{\omega^3 L_2 M^2}{R_2^{\,2} + \omega^2 L_2^{\,2}}\right) \qquad (3)$$

From (3) can be seen that the effective resistance of the network increases with increase in the mutual inductance M. Furthermore, it is clear that the reactive part of the impedance of the network decreases with increasing mutual inductance. With (3), it is possible to constitute the impedance as a function of the deflection of the double-body compression spring. Experiments have shown that a frequency of 250 kHz is particulary suited for determining the deflection of the double-body compression spring. Figure 6 shows the magnitude of the impedance of the network.

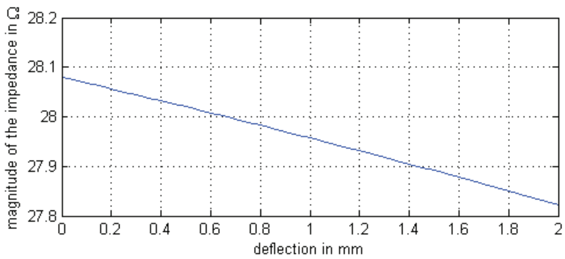

Fig. 6. Magnitude of the Impedance of the network

Figure 6 shows that the change of impedance is very small. Furthermore, it is striking that the magnitude of the impedance is very small. This would mean that the current would have to be very large in order to obtain a useful measuring signal. Therefore, the circuit of figure 5 is modified. Since it is possible to wire the double-body compression spring as well as the receiver coil, it is intended to be used to increase the magnitude of the impedance and the change of the impedance by using electric resonant circuits. The change in impedance is dependent on the current intensity in the double-body compression spring. The inductance of the spring is limiting by the current intensity in the spring. This is compensated by a series capacitance. This has the consequence that the impedance of the spring is limited mainly by the ohmic resistance of the spring. An advantage is that the reactive component of impedance of the spring only consists of the change of the inductance of the spring. With a parallel capacitance on the side of the receiver coil, the impedance of the entire network from figure 5 can be increased. These forms with the receiver coil a parallel resonant circuit, which possesses much higher impedance than the original impedance. The equivalent circuit with the resonant circuits is shown in figure 7.

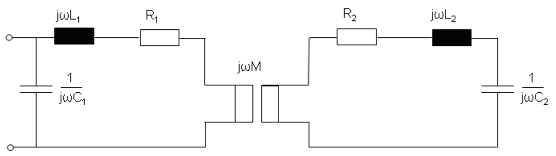

Fig. 7. Modified equivalent circuit

The capacities in figure 7 must be adjusted so that they are adapted to the inductance of the receiver coil and the double-body compression spring. By (4) the capacities can be calculated.

$$C = \frac{1}{4\pi^2 f_0^{\ 2} L} \qquad (4)$$

The result for the parallel capacitance C_1 is 22 nF and for the series capacitance C_2 460 nF. Thus, the impedance of the modified network can be calculated for different deflections. This is shown in Figure 8.

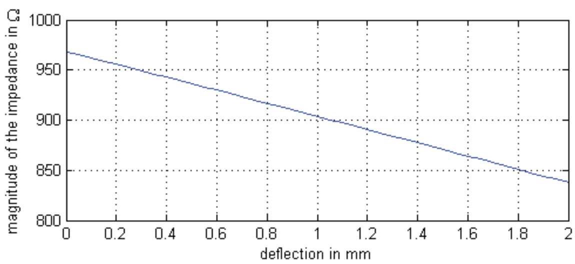

Fig. 8. Magnitude of the Impedance of the modified network

In comparison between figure 6 and figure 8 it is clear that the magnitude of impedance is around thirty times larger than before. Furthermore, it can be seen that the relative change of the magnitude of the impedance has increased. This is advantageous in terms of signal evaluation.

A voltage source with a square-wave signal is used to generate the measurement signal for the circuit. This was chosen, because a voltage source with a sinusoidal output voltage with 250 kHz would mean unnecessary costs. The circuit for generating the measurement signal is shown in figure 9.

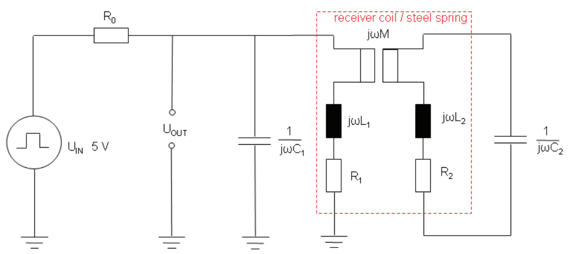

Fig. 9. Circuit for generating the measurement signal

The output voltage V_{OUT} is an almost sinusoidal voltage because the impedance of the network is high impedance for a frequency of 250 kHz. The parts of square-wave input voltage, which have a higher frequency, drops across the series resistor R_0. Therefore, the resistor R_0 is chosen similar in size to the maximum impedance of the remaining network. In this case, a 1 kΩ series resistance was used. The output voltage of the circuit (Fig. 9) is shown in figure 10.

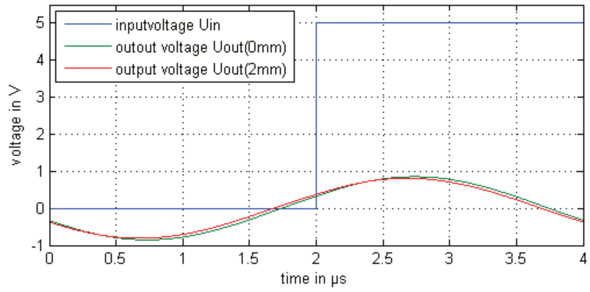

Fig. 10. input (blue) and output voltage for 0 mm (green) and 2 mm (red) deflection

From Figure 10 it is clear that there are two possibilities for the processing of the measurement signal. By the one hand, it is possible to consider the phase shift to the input signal, since the greater the deflection of the spring the higher the phase shift between input and output signal. On the other hand the amplitude of the output voltage can be used because the greater the deflection of the spring is, the smaller the amplitude of the output voltage.

Conclusion and outlook

With the output voltages of the measuring signal, the properties of the spring sensor are known. This makes it possible to perform further planning for dimensioning the digital signal processing. It has been shown that inductive spring sensors can be planned and dimensioned inexpensively using the presented methodology in this paper. It can be said that such spring sensors have great potential for a variety of applications. This is not limited just for the automotive sector.

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