Development of the GMR (Giant Magnetoresistance) Revolution Sensor

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1. Introduction

Improved fuel efficiency of automobiles is becoming increasingly important for environmental reasons, and so complex fuel injection control, ignition timing control, and shift transmission control are needed. In addition, new systems to support early ignition during start-up and to stop idling will play important roles.

Revolution sensors for automobiles are used to detect the operation of the engine or transmission based on the revolution of gears, and to control the engine and transmission. To attain detailed control of the mechanisms, the angle of revolution must be detected very accurately. To develop a new system, detection of revolution conditions (such as the stop position and revolution direction) should be also incorporated.

Mitsubishi has applied a GMR element, which is a high-quality magneto-electric transducer element (to convert magnetic field strength to voltage), to revolution sensors for automobiles for the first time in the world and is now manufacturing the sensors (standard type sensors) commercially [1]. We have also developed and mass-produced sensors that can detect the stop positions of rotation (stop position detection sensors) and sensors that can detect the revolution direction (reverse revolution detection sensors).

This report introduces the line-up of GMR revolution sensors and discusses their technological features.

2. Revolution Sensors for Automobiles

Figure 1 shows the detection system of a typical revolution sensor for automobiles. The system consists of a gear wheel mounted on an axis of revolution (engine crank shaft, for example) and a revolution sensor installed end to end with the gear wheel. The revolution sensor contains a magneto-electric transducer element and a magnet. As the magnetic field formed by the magnet and the gear wheel, which is made of a soft magnetic material, changes as the wheel rotates, the element detects the changes.

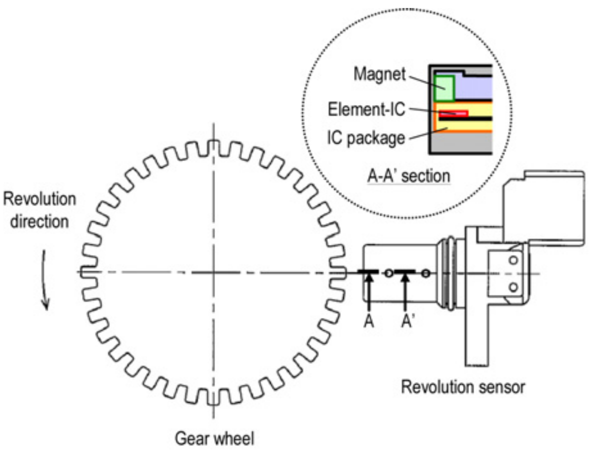

Fig. 1 Revolution sensor detection system for automobiles

3. GMR Revolution Sensor

3.1 Features

To achieve sensors of high accuracy, it is important to obtain signals with a high signal to noise (S/N) ratio. Table 1 shows the performance of the magneto-electric transducer elements used for revolution sensors for automobiles. The sensitivity and the MR ratio of the GMR element are respectively more than 10 times higher than the sensitivity of a Hall element and the MR ratio of a ferromagnetic MR element. In short, a large signal amplitude can be obtained with the GMR element in practical magnetic fields, thus realizing high S/N ratios.

Table 1 Performance of magneto-electric transducer elements

	GMR	Hall	(Anisotropic) MR
NR ratio	Good ≥30%	Good ∞	Fair 2-3%
Sensitivity	good 25 µV/V/(A/m)	poor 0.1 µV/V/(A/m)	good 25 µV/V/(A/m)
Temperature coefficient of resistance	good -1000 ppm/°C	poor -5000 ppm/°C	good -3500 ppm/°C
Thermal stability	good	fair	good
Integration with IC	good	good	good

3.2 Mechanism of detection

Figure 2 shows the MR curve of the GMR element. The magnet inside the sensor generates a bias field in the GMR element. As a tooth of the gear wheel comes close to the element, the magnetic field applied to the element expands, thus reducing the electric resistance of the element.

3.3 Block diagram

Figure 3 shows the basic block diagram of the GMR revolution sensor. The GMR elements constitute

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a Wheatstone bridge. The midpoint voltage level of the bridge is amplified by the differential amplifier and output as a digital signal via the comparator.

4. Line-up and Features of GMR Revolution Sensor

Figure 4 shows the line-up of the GMR revolution sensors.

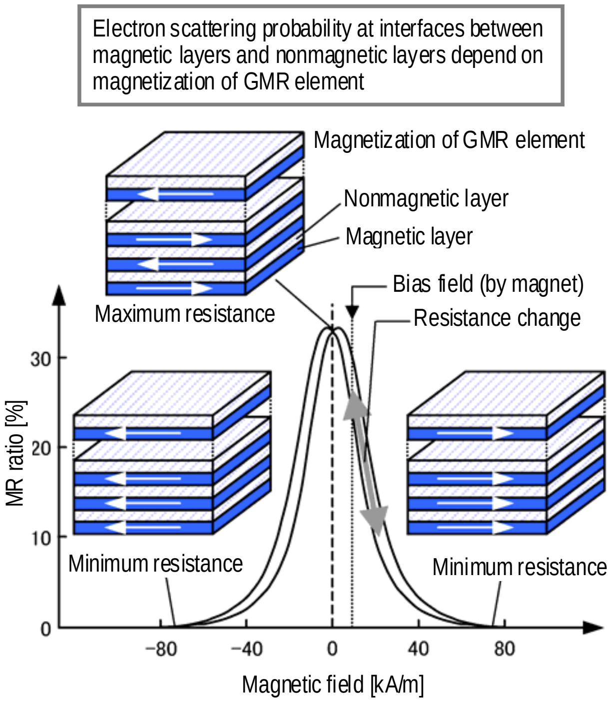

Fig. 2 MR curve of a GMR element

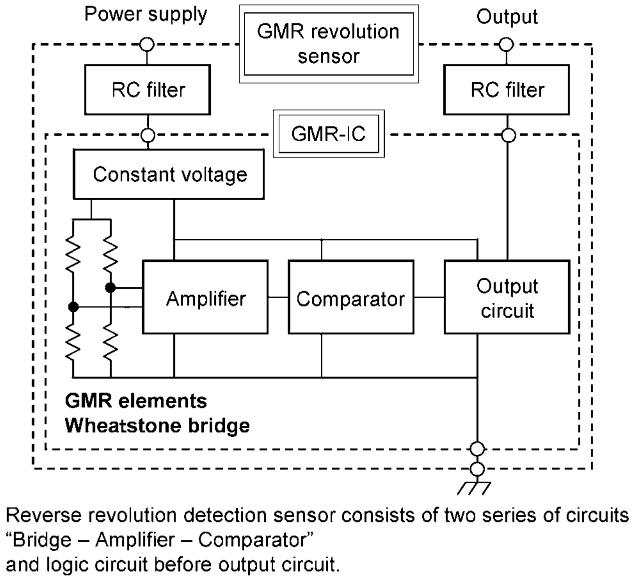

Fig. 3 Block diagram of the GMR revolution sensor

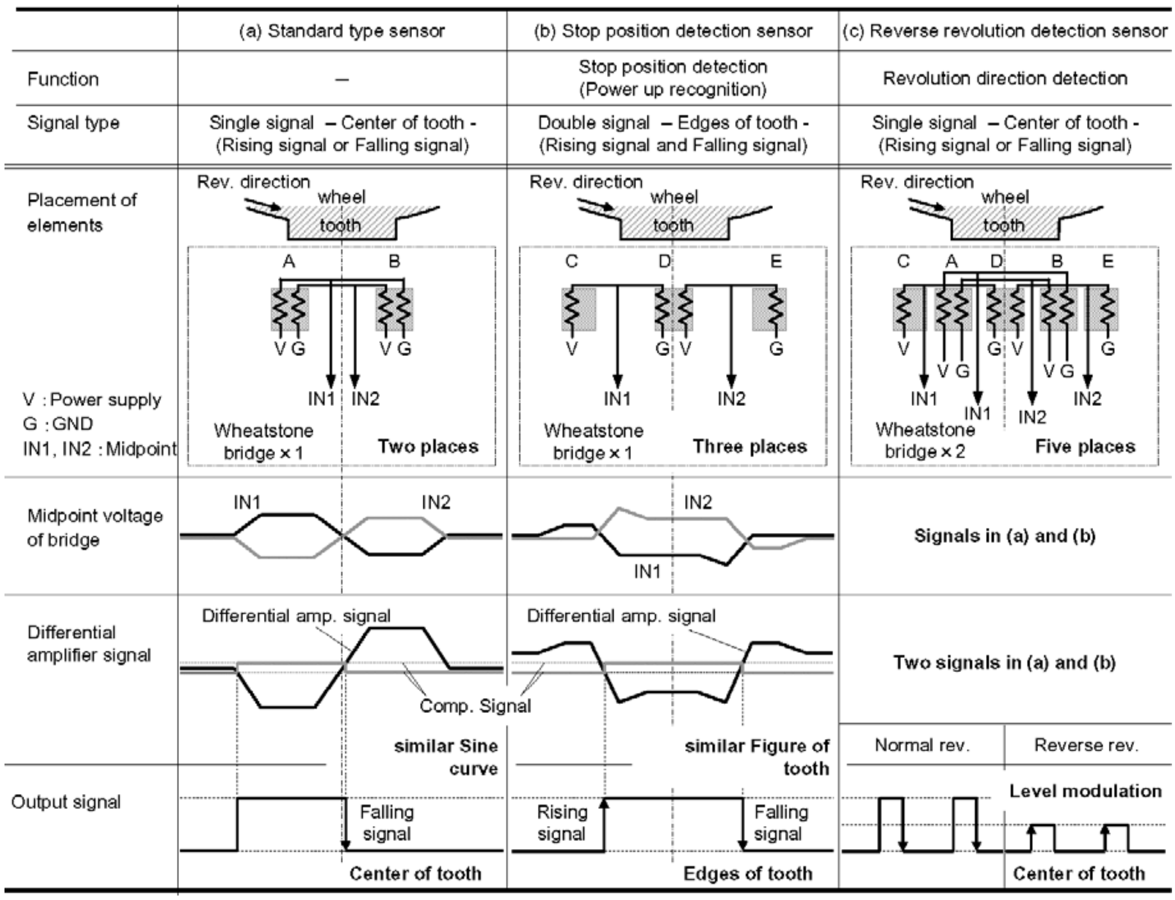

Fig. 4 Line-up and features of the GMR revolution sensor

4.1 Standard type sensor

Figure 4(a) shows the placement of elements and signal form of a standard type sensor. Elements are placed in two positions on the IC and constitute a Wheatstone bridge. When, as a result of gear wheel revolution, magnetic field is applied to the region A and then the region B shown in the figure, for example, the signal for the midpoint voltage level of a Wheatstone bridge, after the differential amplifier (differential amp. signal), changes similarly to a sine curve with the peak level located near two edges of the tooth; consequently, the edge signal[*1] (falling signal shown in the figure) as an output signal from the comparator is output near the center of the tooth. High-accuracy detection results from properly placing the GMR elements of high output to form a Wheatstone bridge.

4.2 Stop position detection sensor

Figure 4(b) shows the placement of elements and signal form of a stop position detection sensor. Elements are placed in three positions on the IC and constitute a Wheatstone bridge. When, as a result of gear wheel revolution, magnetic field is applied to region C, region D and then the region E shown in the figure in this order, for example, the signal for the midpoint voltage level of a Wheatstone bridge, after the differential amplifier (differential amp. signal), changes similar to the shape of the tooth; consequently, the edge signals (rising signal and falling signal shown in the figure) as output signals from the comparator are output near both edges of the tooth. For the signal form similar to the shape of the tooth, the voltage level is output in accordance with the shape, either a tooth or a slot, even when the gear wheel has stopped.

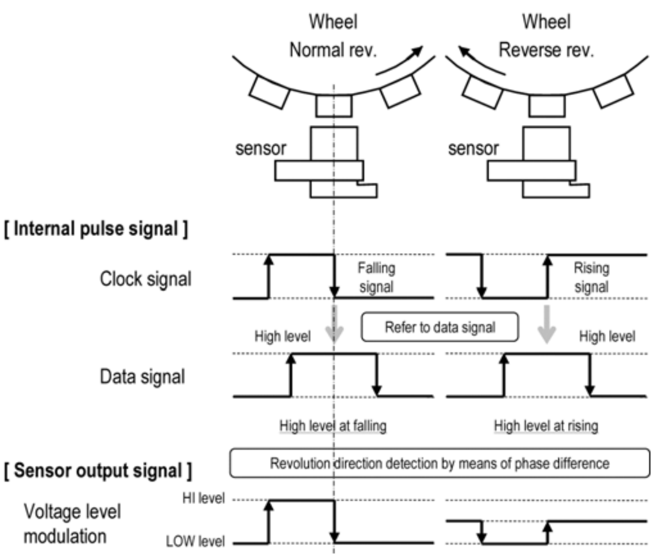

Figure 5 Principle of revolution direction detection

4.3 Reverse revolution detection sensor

Figure 5 shows the principle of revolution direction detection. Two types of signals are required for detecting the revolution direction of a gear wheel. A data signal (reference signal for revolution direction) is detected with the timing of the clock signal and checked, to finally determine the revolution direction (normal or reverse) by the logic circuit. So, these signals are required to have phase differences. The standard type sensor signals (center of a tooth) and the stop position detection sensor signals (edges of a tooth) theoretically have phase differences, and so are suitable for detecting revolution direction.

Figure 4(c) shows the placement of elements and signal form of a reverse revolution detection sensor. Elements are placed in five positions on the IC and constitute two Wheatstone bridges. Region A and region B constitute the standard type sensor element, while regions C, D, and E constitute the stop position detection sensor element. Two types of elements are incorporated in the reverse revolution detection sensor.

The direction of revolution is judged by the logic circuit as mentioned above by means of two signals from the two Wheatstone bridges. The output signals represent the direction of revolution by changing the HI level and/or LOW level in accordance with the direction of revolution (level modulation). With the newly developed sensor, an edge signal is output near the center of a tooth, and so is highly compatible with the standard type sensor, allowing for both high accuracy and revolution direction detection.

We have created highly accurate GMR revolution sensors and improved the related functions. We will modify these sensors for wide application to assist the development of highly efficient and low fuel-consumption power trains.

Reference:

(1) Motohisa Taguchi, et al.: GMR Revolution Sensors for Automobiles, SAE2000-01-0540

[*1] Position signal used for control