[Technical Article]

Development of High Resolution Sensor Element MPS40S and Dual Track Magnetic Encoder for Rotational Speed and Position Measurement

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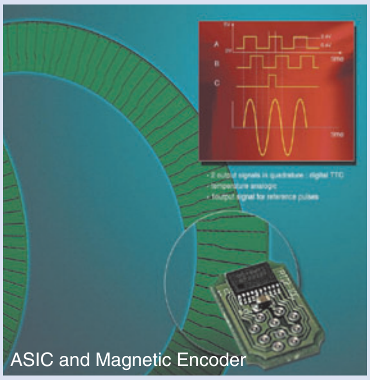
ASIC and Magnetic Encoder

Higher precision and resolution requirements for rotational speed and position sensors in automotive and other applications lead SNR to investigate in the potential of their ASB [1]®-Technology, where magnetic single track encoders have been integrated in wheel bearings and serve together with small active sensors for detecting the speed of each individual wheel of a car. Such information is used for ABS [2], ASR [3], ESC [4] and other car systems.
Based on this well proven technology, which is installed in over 50 million cars now, SNR has developed two new basic components to improve the performance of such sensing systems. The magnetic sensor ASIC [5] MPS40S in combination with a new dual track magnetic encoder provides high resolution speed and incremental position signals, with direction of rotation and additionally the possibility of reference or index signals for absolute position determination.

1. Introduction:

The industrial developments go more and more into electric devices and even traditional mechanical systems become electrically assisted, such as manual gearboxes, steering systems etc.… So the need for precise and reliable sensor is continuously increasing. At the same time the cost factor becomes more and more important. Since SNR has introduced the ASB ® Technology for wheel speed detection in cars, which became a world standard now, the research efforts in that domain have lead SNR to develop not only magnetic encoders with better magnetic material and higher precision, but also sensing elements in order to implement more functionality in the Sensor Bearings. At the SNR Mechatronics Department in Annecy, France, basic developments and research programs are conducted especially for magnetic sensor devices as these are seen as robust and cost effective solutions, which can work even in harsh environment situations. The performance of the latest sensor development is presented in this paper as well as a short overview of the technology.

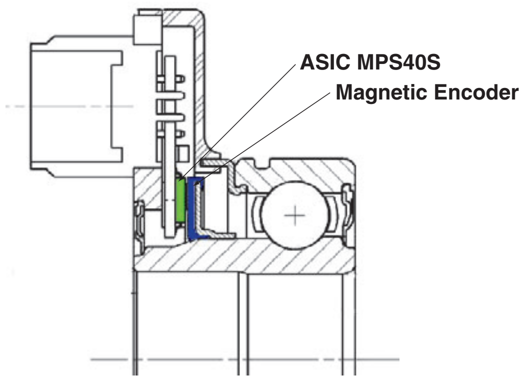

Fig. 1 Section of high resolution sensor bearing

1) Representing "Active Sensor Bearing" named by SNR.
2) "Anti-lock Brake System".
3) "Anti Slip Regulator" or "Anti Skating Regulation system".
4) "Electric Stability Control"
5) "Application Specific Integrated Circuit".

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2. Sensor Components:

2.1. Magnetic Encoder

At the end of the eighties, SNR developed a first magnetic multi-pole encoder, which was integrated in a sensor bearing. Meanwhile such encoders are to be found in many different sensor bearings typically in combination with standard Hall or MR elements. This was one of the basic components of the ASB ® system. The qualification program for the magnetic encoders especially for automotive wheel applications proved the robustness of the design; none of water, salt, mud or small metallic particles could disturb the quality of the signal. Today SNR is introducing a new generation of magnetic encoders with a second track in the same space of the single track encoders. With the second track it is possible to put one or more reference points on the encoder, which indicate an angular position of the encoder. The magnetisation process has been adapted for such dual track encoders, as the magnetic field has to be well controlled in order to minimise the influence from the magnetic poles of the reference track to the high resolution track. **Fig 2** shows the different types of magnetic encoders and the corresponding magnetic fields. Following the points ① to ⑥ show the variation of the magnetic field strength, which is seen by the sensor. Standard Hall or MR (magneto resistor) elements cannot interpret such field configurations and would lead to a false signal. Therefore SNR has developed a new sensing element which shall be described paragraph 2.2.

In **Fig 3** is shown how the magnetic poles look like on a real encoder. At the inner circle of the magnetic encoder the poles are all the same size. On the outer circle this is not the case; the red points indicate the positions where the reference pulse is generated. The poles are visualised with a special magnetic film, so that the two tracks with the phase shift change between the poles can been seen easily. Furthermore it is shown that such phase shift changes, resulting in a reference pulse signal, can be put on every single pole pair of a north and a south pole. The poles are separated by a straight transition line, when a signal shift from 1 to 0 or from 0 to 1 is implemented. On this sample a special pattern of 65 pole pairs is implemented. The position of the reference pulses has been calculated according to the application specification. Theoretically it is possible to put as much reference pulses as pole pairs on a magnetic encoder of this type. SNR developed a special magnetisation process to improve the pitch error that is very important for such a device. The phase shift of the transitions over one pole pair in Y/Z direction is depending on the calculated nominal airgap (X direction) in order to get acceptable mounting tolerances. Field simulations helped to optimise the magnetisation tool, which is specific for different reading diameter and airgap. The standard magnetisation tools do not provide sufficient precision for the dual track encoder.

2.2. Magnetic Sensing Element MPS40S

The magnetic field sensor ASIC MPS40S integrates a first array of Hall elements for high resolution purposes and a second array which reads the second track of above described magnetic encoders in order to create reference pulses. On the MPS40S block diagram, **Fig 4**, some of the features are directly shown. In order to make this device as flexible as possible, some features have been implemented which are patented. The MPS40S can read a wide range of magnetic pole widths, which is new

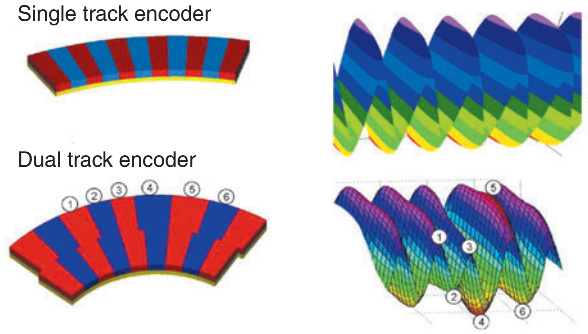

Fig. 2 Scheme of single and dual track encoder

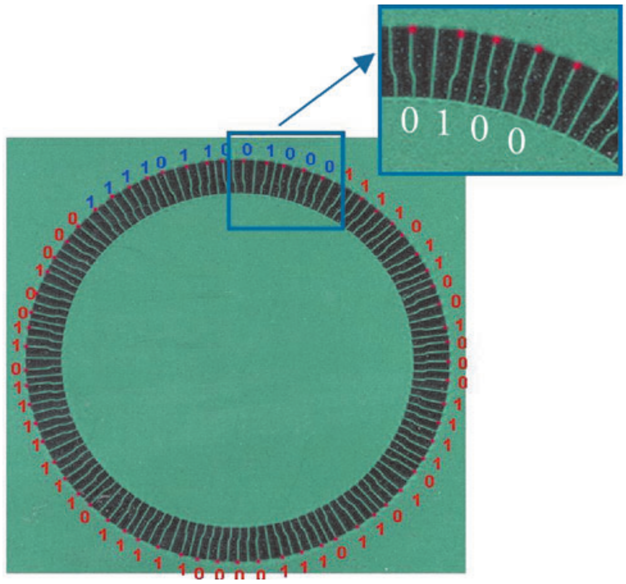

Fig. 3 Magnetic encoder with reference track and signal status

compared to magnetic wheel speed sensors, the pole size can be programmed which makes the reading even more precise. A very special interpolator block on the die of the MPS40S allows raising the resolution over one pole pair. The interpolation factor is also programmable as shown in **Table 1**. Furthermore the MPS40S provides the direction of rotation from 90° phase shifted signals A and B. In parallel such magnetic encoders, which may be integrated in a bearing seal, have been designed by adding a second magnetic track in the same envelope of the series product. The second track is read by the MPS40S simultaneously and provides angular position information of the magnetic encoder. The magnetisation process is done in a way that even existing designs of magnetic encoder seals can be magnetised with the new dual track for existing product improvement. In this case only the sensor head has to be adapted for integrating the MPS40S. For a better understanding the signals are shown in **Fig 5**, where the analogue signals input from both tracks are compared to the digital signals. Reading

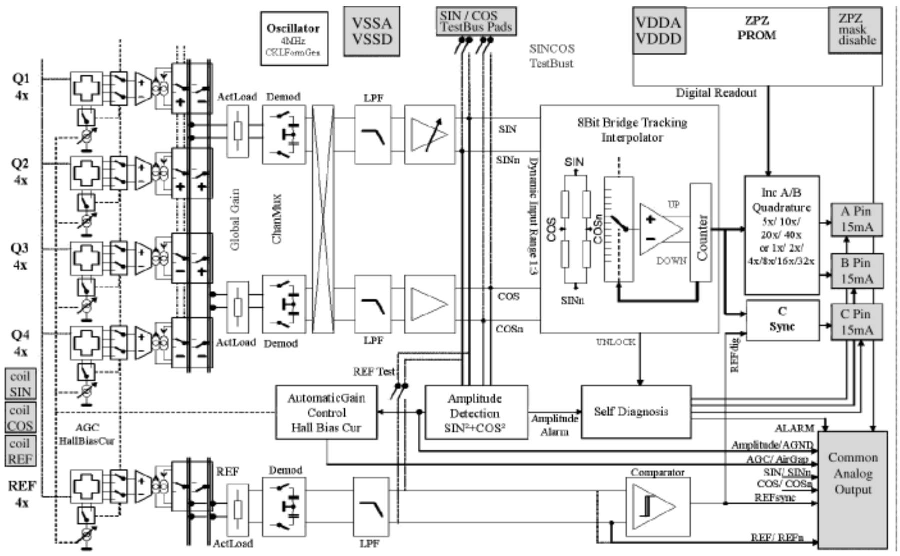

Fig. 4 MPS40S block diagram

Table 1 Interpolation factor programming table

Interpolation	1x	2x	4x	5x	8x	10x	16x	20x	32x	40x
Pulses 1)	32	64	128	160	256	320	512	640	1024	1280
Edges 2)	128	256	512	640	1024	1280	2048	2560	4096	5120
Resolution 3)	2.8°	1.4°	0.7°	0.5°	0.35°	0.25°	0.18°	0.12°	0.08°	0.07°

1) Based on a 32 pole pair encoder　2) Number of raising and falling edges of the signal output lines
3) Resolution, when using all edges of the signals

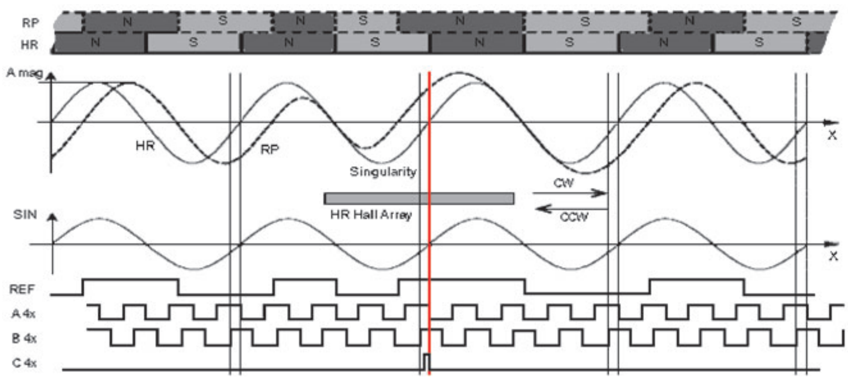

Fig. 5 MPS40S signals

from left to right is the clockwise direction and from right to left the counter clockwise direction of rotation, in any case the reference pulse comes at the same position by internal comparison of the high resolution input and the reference input.

Features of the MPS40S combined with Dual Track Magnetic Encoder:

- **Non contact sensor concept**
- **Compact design, smallest reading diameter: φ35mm**
- **Temperature range: -40˚C to +125˚C**
- **Compatible with harsh environment, dust, mud, water, oil …**
  A lot of tests have been done, when this encoder material has been qualified for automotive applications such as encoder for wheel bearings in cars. All car manufacturers have released our products for such application.
- **Wide range of magnetic pole width: 1.15mm to 6mm, with a pitch of 0.02mm**
  Over the pole width, combined with the interpolation factor, almost all resolutions can be achieved. The pole width is programmable.
- **Flexible design of magnetic encoders, number of pole pairs, …**
- **Automatic Airgap Adjustment, within the detectable magnetic field (≥5mT)**
  In case the detectable magnetic field becomes too small, the MPS40S sets an alarm.
- **Programmable Interpolation Factor: 1x to 40x**
  The different interpolation factors are shown in **Table 1**.
- **Direction of rotation information**
  By reading the A- and B-signal, which are 90° phase shifted. The raising edge which comes first, whether on A or B indicates the direction of rotation (shown in **Fig 5**).
- **Reference pulse information (1 or more on the magnetic encoder)**
  The MPS40S compares the magnetic fields of both tracks, shown in **Fig 5**. On the C-signal line a pulse is sent, when at the Zero-crossing of the A-signal the positive field of the RP-track is above the threshold, as shown on the red line in **Fig 5**. Obviously this can be repeated on every pole pair on the magnetic encoder.
- **Self diagnostic features integrated in the MPS40S**
  As already mentioned, the MPS40S can detect failures concerning the magnetic field out of the detectable range, but also internal failures. In this case the MPS40S sends a failure message via the three output lines.
- **Test bus, for application development purposes**
  The output of the test bus is programmable for analogue and digital signal readings.
- **AEC Q100 qualification**

3. Applications and some examples:

Such a sensor concept can be used in many industrial applications, where speed and position have to be measured on hollow shafts or where the end of a rotating shaft cannot be accessed. As the sensor head is very small and the encoder can be integrated in any rotating part, such as a bearing, applications with reduced available space may be interesting as well.

Steering Angle Sensor, a joint development with Continental Automotive Systems:

Sensor and encoder may be separated or integrated, both designs are under development. First series production developments have been started. In **Fig 6a** the separated version of the steering angle sensor is integrated lower part of the steering system. This is the most effective design in terms of space and cost and it can be even improved if the magnetic encoder can be integrated in a bearing, which is shown in **Fig 7**. Therefore the bearings must have a section, which is big enough to get the encoder, and there must be a "window" to this section where the sensor can read the two magnetic tracks.

For more conservative designs the angle sensor can be packaged in a plastic housing, where airgap is controlled by internal design, shown in **Fig 6b**. The sensor is mounted with screws and the steering shaft goes through the sensor. This takes more space and makes replacement more complicated, as the steering shaft has to be disassembled. Compared to this, the separated design is more convenient as the electronic part of the systems can be taken out easily and the magnetic part, which is mounted to the steering shaft, is not affected. In each case the sensing concept is contactless and does not add any torque to the steering system, neither any noise. Both points are very important for such applications as noise and torque are directly felt by the driver.

EPS motor position sensor:

Sensor and encoder are separated; the encoder is integrated in a ball bearing

The same sensor concept can also be used in the rotor position sensor for electric motors and actuators, such as EPS motors. Because of the high resolution capability of the sensor, this application is

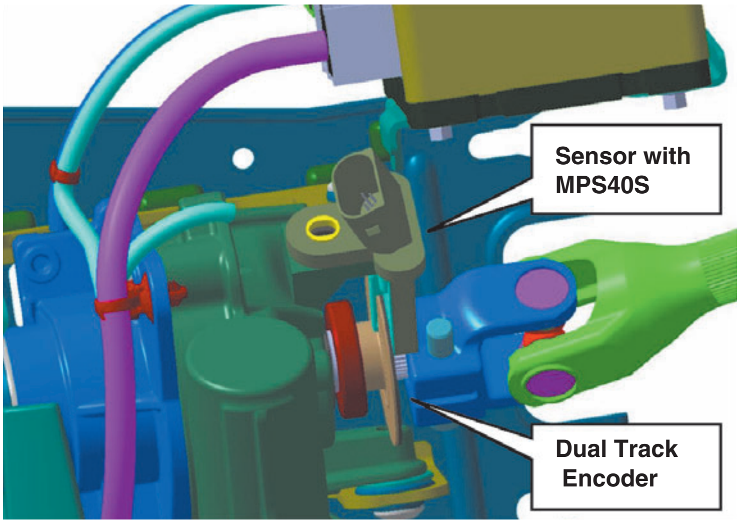

Fig. 6a Steering angle sensor
SNR/Continental automotive systems

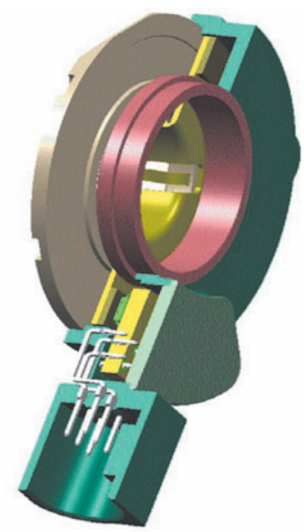

Fig. 6b Steering angle sensor

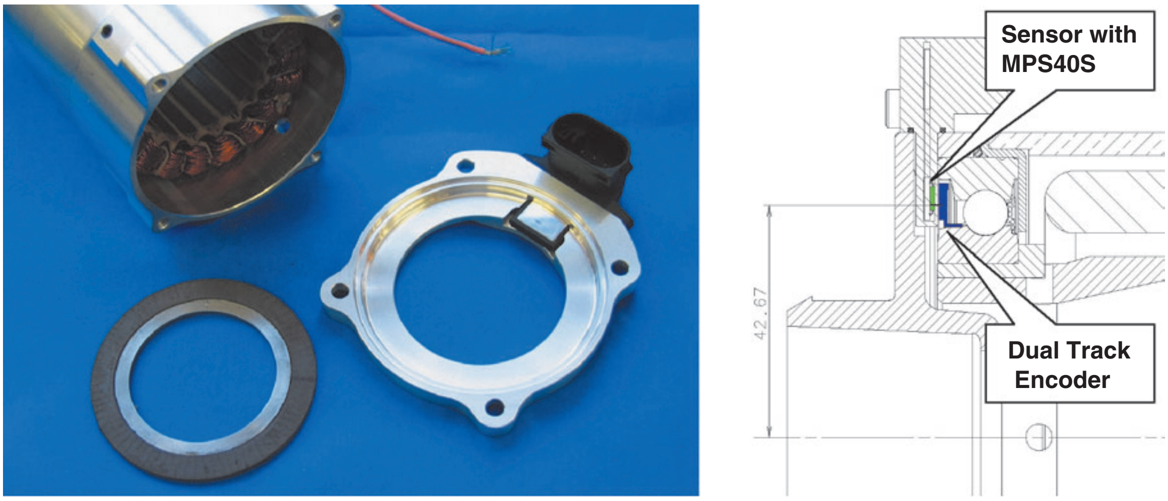

Fig. 7 EPS motor with sensor and encoder bearing

interesting, especially if no sensor can be placed at the end of the motor shaft. The magnetic encoder pattern on the second track is then designed to get absolute position over one electrical period and repeat this pattern for all pole pairs of the motor. Patents have been filed for the special way of the pattern layout for such applications. Even if the sensor is not absolute true power on, with the special pattern the absolute rotor position can be determined within a small angle at power on and from this point the sensor works like an absolute angle sensor. The enormous advantage is again space and weight saving compared to any resolver technology. Furthermore if the motor design has to be changed in terms of number of pole pairs on the rotor, the sensor design does not change, only the magnetic encoder gets a different magnetisation and the programming of the chip may be adapted.

The flexibility of the sensor with the MPS40S helps to accelerate the development of new motors as the programming is done through the Vdd pin. It is very easy to test new configurations without changing the mechanical environment.

High Resolution Sensor Bearing for Industrial Applications

The demand for sensor bearings in Industrial Applications is also increasing and the SNR technology can be applied easily in the same way. However the design should be more integrated to ease assembly and therefore SNR created a first sensor bearing design which uses all functions of the ASIC and fits into ISO dimensions regarding inner and outer diameter of a 6203 deep grove ball bearing. This bearing is available as a prototype as the engineering department at SNR prefers to develop such type of bearing as an integral part of a complete system optimised for the final application in terms of environmental requirements, assembly, space and cost. Our experience shows that too often a standard design does not perfectly fit in the design of the application and we are forced to modify the "standard" product. Today SNR has all the necessary components in order to develop rapidly the product which fulfils the customer requirements at an attractive price.

Fig. 8 Sensor bearing

Radial Sensor – Incremental High Resolution Signals

Finally the last product developed as a standard sensor without bearing, SNR developed the Radial Sensor, which is also using the SNR ASIC. It delivers incremental speed and angle measurement signals. It is not foreseen that this encoder provides the Reference Pulse signal output; however full programming capabilities concerning pole width and resolution are implemented. This sensor works together with radial single track magnetic multi-pole encoders, which can be found on the market. The electrical interface is designed to work with different supply voltages from 5 to 8-30V and the output stages are realised as Push/Pull.

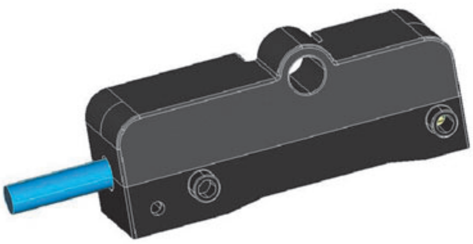

Fig. 9 Radial sensor

4. Conclusions

The newly developed technology by SNR is mainly designed for mass production systems, where the focus is on reliability in first place and seconds the cost. Hall Effect based sensor technology is proven in industry since a very long time and the improvements that SNR has integrated in the ASIC MPS40S make full profit of that background. Furthermore the very long experience in magnetic encoders for applications such as automotive wheel bearings, where water, mud, high and low temperatures are the normal environment, is the perfect base for SNR, who invented that technology and introduced it to the market in 1997, to make the next step in magnetic sensing technology. The very flexible combination of both components by programming of the MPS40S and adapting the magnetic encoders in terms of number of pole pairs, size etc makes it easy to find a solution. The engineering departments at SNR have all the tools to develop the integration of such sensor devices in many applications, even close to strong magnetic fields from electric motors or other harsh environment conditions. With all this benefits, this technology has a very good market potential in many industrial branches.

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