Title: ABSOLUTE ANGLE ENCODER

Abstract: Absolute displacement encoder (1) comprising a segmented (S1-S8) exciter element (47), a receiver element (48) and a relative moving element (49) between the exciter and the receiving element, including a part interfering in the electrical interaction between the exciter and the receiving element, the encoder further comprising an electronic signal source (2,3) connected to the exciter element (47), and an analogue signal processing circuitry (5-10) connected to the receiving element (48). The sensing means (4; 47-49) is produced as a capacitive sensor means, while the signal source (2, 3) is produced with a clock (2) triggered counter (3) such as a Johnston counter, sequentially exciting each exciter segment (S1-S8) with a exciter signal, while the receiver element comprises a receiver segment overlapping with each of the exciter segments (S1-S8) and connected to the signal processing circuitry (5-10).
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
ABSOLUTE ANGLE ENCODER

The present invention relates to an absolute displacement encoder comprising a sensing means with a segmented exciter element, a receiver element and a relative moving element incorporated either rotationally moveable or linearly moveable in the encoder between said exciter and said receiving element, including a part interfering in the electrical interaction between said exciter and said receiving element, and designed for movement with an external object, e.g. by mechanical coupling e.g. via a central shaft in case of a rotary angle encoder, the encoder further comprising an electronic signal source connected to said exciter element, and an analogue signal processing circuitry connected to said receiving element.

Such encoders are generally known. They are produced in various forms, utilising different physical phenomena like optics, induction, magnetics, capacitance, and electronic resistance. All these phenomena are electronically sensed, and processed so as to realise an output in the form of an electronic signal readily usable by an electronic controller.

With the advance of electro-mechanical design in various dynamically operating structures of relatively low capital investments like vehicles, excavator beams and the like, it has become of utmost importance to realise a very low cost absolute angle encoder. Depending on the application it might be of importance to also have a fast and/or highly accurate operating encoder, which features for reasons of costs are most preferably realised simultaneously in one single encoder design.

One such relatively cost effective angle encoder is commercialised by the Beiduncan Company. In the sensor of this company the coupling element is related to the encoder means by an inductive coupling. The coupling features an excitation coil and receiving coil, spatially opposed in a commonly known manner at an operating distance allowing mutual influencing and allowing the in-between passage of a rotating disc of non magnetic sensitive material such as copper, limiting the inductive coupling between the excitation coil and the receiving coils from very little blockage to complete blockage of the signal. The disc is associated with the coupling element and features "windows" of non magnetic material, such that some pairs of coils are influenced while others are not, depending on the angular position of the coupling element. The
Beiduncan sensor features six pairs of coils of which the inductance is electronically read out by the electronic encoding means in sequential manner, which electronic means converts the reading into a sine wave of six parts, whose phase shift varies with respect to the rotation of the rotation disc. The sine wave is fed into a low pass filter and subsequently squared by a comparator. The absolute angle of the coupling elements and consequently of any object connected thereto is then a function of the phase shift of the scanning frequency and the squared sine wave.

The advantage of the Beiduncan principle is the insensitivity to contamination by non-magnetic materials like dust. Another advantage is the immediate conversion of the readings into a digital format. By this feature any said phase difference can easily be converted to a pulse-width modulated (PWM) signal. All of this leads to a relatively fast operating, low cost and readily manufacturable sensor.

A disadvantage of this sensor however, is that due to the inductive principle the sensor maybe disturbed by inductive material around the sensor and possible electromagnetic fields which are of the same frequency as the sensor excitation signal, leading to unreliability.

It is an object of the present invention to overcome the disadvantage of this known sensor principle, while maintaining most if not all of its advantages, at least the cost-effective feature thereof. According to the invention such is favourably realised by an absolute displacement encoder according to the preamble defined above, in which the sensing means are produced as a capacitive sensor means, while the signal source is produced with a clock triggered counter, sequentially excitating each exciter segment with an exciter signal, while the receiver element comprises a receiver segment overlapping with each of said exciter segments and connected to the signal processing circuitry.

With an encoder according to the invention, a low cost sensor is achieved, insensitive to inductive materials for magnetic field from the environment application, while simultaneously the sensor is sufficiently fast and accurate for a very wide range of applications. In the sensor according to the invention a capacitive sensing principle is applied known per se, e.g. from the WO 9509349 patent publication, and from various subsequent publications on this subject by the Delft University of Technology (NL), including "Integrated Interfaces for Low Cost Multiple Sensor Systems", in J. of Intelligent Material Systems and Structures, Vol. 10 - Feb. 1999. The disadvantage of
the said known capacitive method is that it requires a micro controller for A/D conversion and for calculations, which is for small micro controlled sensors a time consuming operation.

The above said capacitive sensor principle uses a rotating dielectric disc. For absolute sensing the dielectric disc is configured with distinctive circumferential sections, each subdivided in a number of segments, e.g. pie shaped, allowing a coarse and a fine reading. The capacity in this principle is measured differential at two places at 90 degrees spacing, which measurement is also known as the quadrature sine/cosine measurement. Thus four capacitances C1 to C4 are read out. The sine value is thus achieved as the subtraction of values C1 – C3, while the cosine is correspondingly achieved as C2 – C4. The actual angle can be calculated by taking the arc tangent of the sine/cosine. These sine and cosine values can be measured easily by using a well-known charge amplifier.

In the arrangement according to the invention the favourable features of both encoder principles have been combined by the replacement of the inductive coil means of the Beiduncan sensor for a modified version capacitive sensor means, in which the receiver element has at least, and preferably at most, one single receiver segment which overlaps all of the exciter segments as seen in plan view. In this manner both a simple encoder means and a relatively simple electronic circuit may be applied in the sensor as indicated by the claims and the description.

The invention will now be further elucidated by way of example according to a drawing in which:

FIGURE 1 is a schematic representation of the encoder according to the invention;

FIGURE 2 is an alternative embodiment of the encoder according to Figure 1;

FIGURE 3 is a schematic representation of a specific, favourable embodiment of the encoder according to the invention;

FIGURE 4 is a schematic representation of an alternative pattern of excitation of the encoder means.

In the figures corresponding elements are identified by identical reference numbers.

Figure 1 schematically represents an encoder 1 according to the invention, comprising a master clock 2 and a Johnston counter 3, which by counter parts b1–b8
sequentially provides individual excitation signals 21 at a predetermined frequency, sequentially to respective pie-shaped segments S1-S8 of an exciter disc 47 of a capacitive sensing means 4. The capacitance means 4 comprises an exciter disc 47, alternatively denoted transceiver disc, a receiver disc 48 and an intermediate rotating
disc 49 rotating about a shaft 46 to which an external moving object may be connected, as more clearly depicted in the embodiment of Figure 2. The number of pie shaped segments in such arrangement according to the invention should be at least 3. It is remarked that the principles explained here are correspondingly applicable to a linear sensor by appropriately adapting the related components in the manner known per se.

The rotating disc 49 between the excitation disc 47 and the receiver disc 48, alternatively denoted sensor disc, is provided with an eccentric circular 44, either of a specific dielectric layer or of a conductive layer. The circular 44 may be embodied by any circularly shaped form, effecting an increase of covered segment area in a sinusoidal pattern. Thus the sensor disc 49 could e.g. also be produced inversed, i.e. as a dielectric layer disc having a circularly shaped eccentric opening. The sinusoidal pattern may also be created by a number of areas effecting such pattern in combination. The receiving disc 48 is a round conductive plate and is connected to the input of a charge amplifier 5.

The excitation signal will generate charge pulses 21 on the receiver plate and charge amplifier. The charge amplifier 5 signal will be depending on the capacitance between the relevant exiting pie segment S1-S8, the rotating disc 49 and the receiving plate 48. Due to the fact that the rotating dielectric pattern has an out of centre placed circular shape the output pulse of the charge amplifier will have a discrete sinus waveform, build up in a number of steps or blocks, equal to the number of excitation pulses and pie shaped segments (8 as shown in the example).

The output signal of the charge amplifier 5 will through a band pass filter 7 be provided with a sinus shape. The band pass filter 7 is used to reconstruct the sine wave signal and to eliminate disturbance signals outside the used excitation- and/or rotational frequencies of the encoder. This sinus signal will then be passed through a comparator 11 which will then produce a square wave signal. This square wave signal will change proportional in phase with the excitation frequency when the sensor disc 49 (with dielectric pattern 44) is rotated.
Comparing the phase of the comparator output signal with one of the excitation
pulses by a pulse width modulation generator 26 will give a pulse width modulated
(PWM) signal 25 which is linear with the absolute angle of the sensor disc 49 (see Fig.
2).

In one arrangement for embodying the above principle, a charge amplifier
known per se is favourably utilised for receiving the signals of the receiver disc 48. It is
in this arrangement solely provided with a capacitance element coupled in parallel with
a transistor element. The resulting output signal is fed through a band filter 7, and
subsequently through a comparator circuit 11 and a pulse width generator for providing
a pulse width modulated (PWM-) signal.

One embodiment of such PWM generator known per se is depicted in figure 1
and comprises two D-flipflop elements 12, 13 and an XOR element 14 outputting
PWM signal 15. The comparator 11 is in this example embodied by a transistor element
8 of which one leads is grounded. A resistance element 9 is in this example coupled
between the output side of the transistor 8 and the ground connection of the element 8.
Another embodiment is having the electronic circuit means of the sensor means being
integrated in an ASIC chip (Application Specific Integrated Circuit).

In the above described set up, eight instead of six segments as known from e.g.
the inductance sensor of the Beiduncan company are used. This could however also be
three segments. Practically a maximum of 64 segments is preferred. With the
introduction of a capacitive means 4 it has become easier to add additional segments
compared to the inductive principle. The benefit of having more segments is that it
makes the band filtering easier to be performed and that in principle it increases the
accuracy and/or linearity of the sensor 1. The band pass filter however reconstructs the
sine wave and also filters away all "noise" signals outside the frequency applicable for
the signals used. Also, the scanning action can be executed faster since the capacitive
measurement is immediately converted to an analogue voltage in the charge amplifier
5. Contrary to the novel set up, the inductive principle usually requires an amplitude
demodulation of the excitation frequency. Further, it is noted that the phase shift varies
with respect to the rotation of the coupler "shading" the electric interaction between
exciter and receiver means. However, also a two plate design may be applied, having
the exciter and the receiver means combined onto 1 PCB (printed circuit board) and
having another PCB with a shaded eccentric form for coupler. In the arrangement
according to the invention, the scanning electronics may further be favourably realised by the application of low cost digital electronics, i.e. CMOS circuits. In such further elaboration of the invention, schematically depicted in figure 3, the analogue components utilised are advantageously only composed by a charge amplifier 5, a band pass filter 7 and the comparator 11.

Figure 3 represents a further embodiment of an encoder 1 according to the invention, having a true digital output. It comprises a PAL (programmable array logic) element 20, clocked by a clock element 19, the output of which is inputted to the PAL element 20. The PAL element 20 may be composed by either a CMOS programmable logic device (CPLD, EPLD, CMOS PAL (programmable array logic), or comparable type of integrated circuit (IC) and is preferably embodied with minimally a 10-bit counter. It comprises a phase trigger which reads the value of the ten or more bit counter into a corresponding number of latches, the contents of which is in this embodiment e.g. transferred in two serial RS232 bytes. The PAL element 20 outputs excitation pulses 21, the result of which is via the receiver plate 48 of a sensing means 4 is coupled to the input line 22 of the analogue circuit 5-11, the output 23 of which is connected to an input of the PAL element 20. An output 24 of the PAL element 20 is a Pulse Width Modulated (PWM) signal, while another digital output 25 of the PAL 20 is a ten (10)- bit number, representing the absolute value of an angle measured by the encoder 1.

In the novel arrangement according to figure 3, the scanning is driven by the three lowest bits of the ten (10)- bit counter. The phase difference is then measured by latching this counter at the positive or negative edge of the comparator output signal 23. The ten (10)- bit counter values provide a 10 bit, or digitally 1024 bit resolution, representing 360 degrees of absolute angle measurement by the encoder 18. The design according to figure 3 is favourable since it allows increase of measuring resolution by using a bigger counter having e.g. 12, 14 or 16 bits. For a very wide variety of applications however the resolution of the lower bit value suffices.

Another advantage of the elaboration according to figure 3 is that the CPLD circuitry is able to provide a number of different output formats like Pulse Width Modulated signals, Serial 10 bits or more signals in direct synchrony or asynchrony, RS 232 signals compatible in two bytes of data with or without a parity bit, emittable at various baud rates. The programmable Logic 20 also allows the generation of an
alternative excitation pulse scheme. In this pulse scheme the segment measurements are made differentially by measuring the differential capacity of two opposing segments e.g. 1-5, 2-6 for an eight segment exciter. See figure 4. Another embodiment of the PAL 20 is a binary decimal counter (BCD) to generate a decimal number instead of a binary angle data.

The encoder according to the invention has an advantage that no computing step is needed since it operates on the basis of a phase shift in the received and processed signal. Alternatively explained, the number of counts of the counter fitting the phase shift of the PWM signal determines the absolute measure for displacement of the sensor disc. Thus a highly accurate value is achieved by this method since the integration of the counter 3 and the PWM generator in the PAL IC guarantee an excellent synchronisation. Also, since the counter value is directly read out in the IC circuit, a highly reliable encoder is achieved, independent from environment factors such as humidity or temperature, since these only affect the signal strength, not the phase shift thereof which is decisive for the present measuring principle.

In a preferred embodiment a switch capacitor is included in the analogue signal processing circuit. Thus the filter characteristic is made linear with the clock speed, so that via the IC-element easily, i.e. without modifying the circuitry lay out of the encoder, one or both of the scanning frequency and the number of bits of the counter (3) may be adapted. E.g. the frequency could be updated for a fast scanning at low resolution of displacement measuring, while both may be increased for increasing resolution at high scanning rates.

Another advantage compared to known encoding methods is that for acquiring a signal, all segments, i.e. a multiplicity of segments, are read out for generating a signal, rather than one or a differential pair of segments. In the encoder according to the invention the absolute measure for displacement of the sensor disc, alternatively denoted coupler disc, is determined by the exciter base frequency and the phase of the reconstructed sine wave from the analogue processing circuit. At a predetermined instant, e.g. when the PWM signal passes zero, the counter value is read, which is a value for the angle or amount of linear displacement as the case may be.

The invention not only relates to what is mentioned in the preceding introduction to the invention and the description of the drawing, but also to all self explanatory or evident details of said drawing, as well as to all details of the following claims.
CLAIMS

1. Absolute displacement encoder (1) comprising a sensing means (4; 47-49) with a segmented (S1-S8) exciter element (47), a receiver element (48) and a relative moving element (49) incorporated either rotationally moveable or linearly moveable in the encoder between the exciter element and the receiving element, including a part interfering in the electrical interaction between the exciter element and the receiving element, and designed for movement with an external object, e.g. by mechanical coupling e.g. via a central shaft in case of a rotary angle encoder, the encoder further comprising an electronic signal source (2,3) connected to the exciter element (47), and an analogue signal processing circuitry (5-11) connected to the receiving element (48), characterised in that the sensing means (4; 47-49) is produced as a capacitive sensor means, while the signal source (2, 3) is produced with a clock (2) triggered counter (3), sequentially exciting each exciter segment (S1-S8) with an exciter signal, while the receiver element comprises a receiver segment overlapping with each of the exciter segments (S1-S8) and connected to the signal processing circuitry (5-11).

2. Encoder according to claim 1, characterised in that the analogue processing circuitry comprises coupled in series a charge amplifier element (5) receiving signals form the receiver disc, a filter element (7), and a comparator element (8).

3. Encoder to claim 1 or 2, characterised in that the receiver element (48) has at least one single receiver segment which overlaps all of the exciter segments at least substantially in whole as seen in plan view, and which is connected to the signal processing circuitry.

4. Encoder to claim 1, 2 or 3, characterised in that the encoder is configured so that the moving element can rotate by at least 360 degrees relative to the exciter element and receiver element.

5. Encoder according to any of the preceding claims, characterised in that the rotating disc is provided with an eccentric circular (44), either of a specific dielectric layer or of a conductive layer, the circular shape being of any circularly shaped form effecting an increase of covered segment area in a sinusoidal pattern.

6. Encoder according to any of the preceding claims, characterised in that a two plate design is applied, with the exciter and the receiver means combined onto 1 PCB
(printed circuit board) and having another PCB with a shaded eccentric form for coupler.

7. Encoder according to any of the preceding claims, characterised in that the phase shift varies with respect to the rotation of the coupler "shading" the electric interaction between exciter and receiver means.

8. Encoder to claim 5 characterised in that the sinusoidal pattern is created by a number of areas effecting such pattern in combination.

9. Encoder according to the any of the preceding claims, characterised in that the filter element (7) is a band filter.

10. Encoder according to any of the preceding claims, characterised in that the encoder comprises connected in series to the analogue signal processing means, a pulse width modulated signal generator (26), outputting a pulse width modulated (PWM-) encoder output signal.

11. Encoder according to the preceding claim, characterised in that the pulse width modulated signal generator (26) additionally has an input formed by one of the excitation pulses (21) provided by the signal source means (2, 3).

12. Encoder according to any of the preceding claims characterised in that the PWM signal is realised two D-Flip-Flop elements (12, 13) each receiving a PWM generator input signal and each outputting to an XOR element (14).

13. Encoder according to any of the preceding claims characterised in that the electronic circuit means of the sensor means is being integrated in an ASIC chip (Application Specific Integrated Circuit chip).

14. Encoder according to any of the preceding claims, characterised in that the number of segments (S1-S8) of the exciter element (47) is three ("3") or more.

15. Encoder according to any of the preceding claims, comprising a signal outputting means (11-13), characterised in that the signal source means (2, 3) and the signal output means (11-13) are incorporated in an integrated circuit (IC) element (20).

16. Encoder according to the preceding claim, characterised in that the IC element (20) is produced as one of a PAL, a CPLD, an EPLD or a CMOS circuit.
17. Encoder according to claim 15 or 16, characterised in that the IC element (20) comprises a bit – type counter having a minimum of four (4) bits.

18. Encoder according to claim 15, 16 or 17, characterised in that the programmable Logic (20) also allows the generation of an alternative excitation pulse scheme in which the segment measurements are made differentially by measuring the differential capacity of two opposing segments e.g. 1-5, 2-6 for an eight segment exciter.

19. Encoder according to claim 8 or 9, characterised in that the PAL (20) is a binary decimal counter (BCD) to generate a decimal number, directly representing the amount of movement of the moveable element, e.g. as the angle of rotation thereof.

20. Encoder according to any of the claims 14 to 19, characterised in that the lowest bits of the counter embodied in the PAL (20), e.g. the lowest three bits in case of an exciter element of eight segments, are used for sequentially triggering the respective segments of the exciter element.

21. Encoder according to any of claims 14 to 20, characterised in that the IC-element (20) is triggered by a serial clock-element, e.g. operating at 1 MHZ in combination with a ten ("10") bits counter.

22. Encoder according to any of the claims 15 to 21 characterised in that the output signal of the signal processing means is registered by the IC-element (20).

23. Encoder according to any of the preceding claims, characterised in that a switch capacitor is incorporated in the analogue signal processing circuit.

24. Encoder according to any of the preceding claims in which the relative moving element has a di-electric active pattern effecting a sinusoidal increase or alternatively decrease of the area of a segment covered by the moving element.

25. Encoder according to any of the preceding claims, characterised in that the IC element circuitry processes a latch contents read from the counter before it is outputted, so as to provide an output signal like one of a PWM signal, a serial multi-bit signal, or an RS232 signal compatible in two or more bytes of data.

26. Method of measuring absolute displacement, utilising capacitive encoder means, in particular utilising an encoder according to any of the preceding claims, performing the steps of comparing the phase of a reconstructed sine wave with the
excitation pulse sequence, and linearly relating the resulting difference between the excitation signal and the reconstructed sine wave to the absolute position of the sensor disc of the encoder.
### A. CLASSIFICATION OF SUBJECT MATTER

**IPC 7**

G01D/241

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

**Minimum documentation searched** (classification system followed by classification symbols)

IPC 7 G01D G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>US 5 681 990 A (LEE WILLIAM HENRY ET AL) 28 October 1997 (1997-10-28) column 3, line 19 -column 4, line 44; figures 1,2</td>
<td>1-4; 7-11, 14, 24, 26</td>
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Further documents are listed in the continuation of box C. Patent family members are listed in annex.

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20 November 2002

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