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Apparatus for torque measurement on rotating shafts

This invention describes a new method for measuring the angle of torsion on loaded rotating shafts. When the angle is known it is possible to calculate the torque and the power as the RPM also will be known or measured.

The most used method for measuring the power on rotating shafts used in various types of machinery has until now been done by the use of strain gauges glued to the shaft. The signals measured by the strain gauges have been transferred to the instrument electronics and the display by means of sliprings or telemetry. When telemetry is used it is necessary to have a transmitter mounted on the rotating shaft and powered by a rotating battery, or in newer systems, wireless transfer of power to the strain gauge electronics on the shaft.

A later system uses so called magnetic hall effect sensors. The sensors pick up signals by means of two gearwheels which are placed on the shaft in an adequate distance from each other. When the shaft is loaded there will be a time delay between the pulses detected by the two hall effect sensors each of which is sensing on a gearwheel. The time delay between the pulses determine the torsional angle of the loaded shaft. A similar system to this is described in the publication "Antriebstechnik" 33 (1994) No.8 page 53: "Entwicklung eines robusten berührungslosen Drehzahl-Drehmoment-Messsystems".

US Patent No. 4.520.681 is a system which uses a pulstrain principle with rotating coders in an adequate internal distance from each other and mounted to the shaft. The torsional angle is measured by means of the time delay between electronic pulses. Two sensors are mounted in an adequate distance from each other, one sensor at each rotating coder. The said time delay between the pulses from the said sensors is measured in electronic counting circuits. In the US Patent No. 4.520.681 either optical or magnetic sensors are used. This system uses similar or identical principles to the system as described at page 53 in the publication "Antriebstechnik" 33 (1994) No.8.

The above mentioned systems have the common principle of operation that they will have to use two electronic sensors to make it possible to detect the torsional angle of a loaded shaft.

To achieve a sufficient accuracy in systems using two sensors placed at a distance from each other it is necessary that the triggerpoints of the sensors do not drift from each other. Ageing and/or temperature variations may cause the triggerpoints to drift from each other and possibly in opposite directions.

The invention described herein uses only one single sensorsystem to measure the torsional angle of a rotating loaded shaft. This eliminate that the measured time delay between the sensed pulses

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can drift and thus causing inaccuracies to occur. This invention presents itself as a new system which has a high degree of accuracy and longtime stability.

These characteristics mentioned are described in the invention claim No.1 :

Apparatus for measurement of the torque of rotating shafts by measuring the pulse width generated two vanes (3a), (3b) which are mounted to the shaft (4) at a suitable distance from each other and characterised by measuring the torsional angle by means of a narrow lightbeam (2) which is being pulsed by the said vanes (3a, 3b) and that all information on the said torsional angle are in a series of width modulated light pulses which are received by a light sensitive electronic detector producing electronic pulses that can be stored in a computer memory in order to be processed and that the torque of the shaft can be displayed on a monitor.

Fig.1 shows the apparatus with one lightsource as the transmitter and a light sensitive electronic sensor as receiver. The light source, functioning as the transmitter, may be a LASER source or a LED (Light Emitting Diode). From the transmitter (1) there is a narrow light beam (2) radiated parallel to the rotating shaft (4).

During the shaft rotation the lightbeam will be interrupted by the vanes (3a) and (3b) which are mounted to the shaft in an adequate distance from each other. The light pulses generated in this way are received in (5) named the receiver. The light sensitive electronics (6) generate the electronic pulses. When the shaft is loaded the vanes (3a) and (3b) will be displaced an angle equivalent to the torsional angle.

The light/dark time increases from the time t unloaded till $t + \Delta t$ loaded. This principal is illustrated on fig.4 showing the vanes (3a) and (3b) mounted to the shaft and displaced a time Δt to each other.

Fig.2 shows an example using fiberoptic cable (9). The beam from said cable is interrupted at the vanes (3a) and (3b). The lightbeam is transmitted from the source (1) crossing the space at (3a) and is further picked up by the optical receiver (7), transmitted through the fibre optical cable (9), the optical lens (10) and across another space at (3b) to the optical receiver (11) which is connected to the light sensitive receiver (6) with internal pulsgenerating electronic circuits. By using fiberoptic cable for the light transmission, obstructions like bearings etc. fig.2 (8) can be passed. This make it possible to enlarge the distance between the interrupting vanes and to increase the accuracy of the measurement.

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Fig.3A shows an arrangement with two coding discs or gearwheels used for lightbeam modulation. As shown on fig.3A the lightbeam is transmitted from a source (12) indicated S/M through the fibre cable (13) to the optical transmitter/lens (14). After the lightbeam (15) has passed the rotating pulse modulating disc (16), it is received by the optical receiver (17) which in turn transmits the puls modulated lightbeam through the connected optical fibre (18) and further through the lens (19). The lightbeam (20) passes through the rotating disc (21) and is received by the optical receiver (22) from which it is retransmitted through the optical fibre (23) to a light sensitive sensor (12) indicated as S/M. In this way the lightbeam is pulsed into a great number of pulses each turn of the shaft. The displacement between the teeth of the two coding discs (16) and (21) determines the pulse width which is a measure on the torsional angle, the torque and the shaft power.

Fig.3B shows the complementary arrangement to fig.3A. In fig.3A is the lightbeam (15), (20) transmitted through the fiber arranged in a serial configuration as it will have to pass the two spaces at (16) and (21). In the arrangement shown in fig.3B the lightbeam transmitted from the source (12) is splitted in two parallel beams. The light which is transmitted through the fibre (24a) passes the gap (26) and the disc (16a). A second similar lightbeam passes the gap (30) and the disc (21a). Both lightbeams (26) and (30) are pulsed by the discs (16a) and (21a) respectively. The discs (16a) and (21a) are inverted compared to the discs (16) and (21) fig.3A. The discs (16a) og (21a) are identical and have narrow light openings and wider vanes. An adequate relation between openings and vanes is 1:4. The puls modulated light is transmitted through the fibres (28a) and (28b). The two pulsed lightbeams are added in the optical summing unit (32). The resulting output from (32) will be a puls width modulated lightbeam which in turn is transmitted to the light sensitive electronic receiver (12) named S/M on fig.3B.

Both the arrangements as shown in the fig.3A and 3B will in principle give identical information to the light sensitive receiver and detector in (12). The arrangement fig.3B is preferred because of the lower damping of the light, compared to the arrangement in fig.3A. The lightbeam is splitted in two parallel paths, each beam will have only one space of air to pass. In addition it is preferable to use narrow light openings and wider vanes as shown on fig.3B to avoid an offset signal in the light pulses out of the adder (33) after the summation of the pulses from (28a) and (28b).

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Fig.5 (34) and (35) illustrate the lightpulses after having passed the disc vanes indicated as $A_1 \dots A_n$ and $B_1 \dots B_n$ on the two discs fig.3A (16) and (21). As will be seen from fig.3B the discs/gearwheels (16a) and (21a) are the inverted mode of (16) and (21).

Both discs/gearwheels attached to the same shaft are congruent and spaced an adequate distance from each other.

The mutual position of the discs/gearwheels (16) and (21) are uncritical with unloaded shaft. They are normally mounted in a position with $B_1 \dots B_n$ falling in between $A_1 \dots A_n$ and in a way that overlapping is avoided during loading of the shaft. This situation is illustrated on fig.5 (34) and (35). When the shaft rotates the light sensitive sensor (12) will receive lightpulses as shown on fig.5 (36). If the shaft is unloaded, there will be a time displacement indicated t between the teeth A and B of the two discs/gearwheels. When loaded this time displacement will increase to $t + \Delta t$, where Δt expresses the rate of loading.

The lightsignals received by the light sensitive sensor/receiver (12) fig.3A or fig.3B generate width modulated electronic pulses. The pulse width modulation are generated by measuring the time between the raising pulse edges and similarly also the time between the falling pulse edges.

Fig.5 (37) illustrates pulses generated by the raising edges of A and B. Fig.5 (38) illustrates similarly the falling edge pulses. This mode of pulsegeneration doubles the number of pulses each turn of the shaft and will be exactly twice the number of teeth on the discs/gearwheels.

Both series of width modulated pulses (37) and (38) are accumulated in the fast electronic registers.

The sum of the time duration is averaged and updated at suitable number of turns of the shaft or time intervals.

When the offset time t , which is the time displacement unloaded, is zeroed, the displacement time Δt is calculated by averaging the accumulated content in the registers after suitable time intervals. The updating of the time Δt can be done to selectable intervals.

Calculation of the RPM is carried out by counting the clockpulses of one turn of the shaft. As a rather high clockfrequency is used to drive the counters the measurement of the RPM has a high degree of resolution and accuracy.

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The averaged time displacement Δt , the measured RPM and the knowledge of the steel parameters of the shaft make it possible to calculate the torque and the shaft power.

A practical arrangement of this invention can be carried out as illustrated on fig. 6. The light is transmitted from the source S (45) through the splitted fibres (24a) and (24b). The two beams pass through the U formed spacings (39) and (40). The air gaps in the spacings are in the order of 5 - 10 mms. Similarly to the arrangement as shown on the figures 3A and 3B the said light beam is pulsed by the rotating discs which are supplied with suitable teeth/vanes passing the gap in the U-shaped sensors.

After having passed the two air spacings (39), (40) the pulsed light beams are collected in the light adding element (32). The sum of the beams are transmitted through the fibre (33) to the light sensitive receiver (41). The shape of the light pulses are illustrated in fig. 5 (36). The receiver is a light sensitive detector with a very short fast response. The electronic output pulses from the detector are signals at TTL level. These realtime signals are processed in the extremely fast PLD counting circuits (47) in which the information is preliminary stored and used for the averaging and updating of the measured torsional angle. This process is controlled via a duplex RS485 communication line by a standard PC (49).

To eliminate inaccuracies caused by periodic movements like vibrations etc., the signals expressing the torsional angle are summed and averaged after a selected number of turns of the shaft.

The data measured and calculated in the way described above are sufficient for an accurate calculation of RPM, torque and power.

RPM, torque and power are presented both graphically and digitally on the PC monitor (50) and/or on a LCD display.

The great advantage of this invention is its use of one light source and a single light sensitive electronic detector only. In the arrangements shown on fig. 3B and fig. 6 two independent light sources may be used to feed light into the optical fibres (24a) and (24b). The use of one or two light sources is a question of convenience. An outstanding feature of this invention is the use of optical fibres to feed light from the transmitters to the single light sensitive electronic receiver/detector. The said arrangement has the great advantage that the coding discs may be mounted to the shaft at the most convenient distance from each other.

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As described above the two sensing points i.e. the two discs/gearwheels can be mounted to the shaft at a great distance from each other by the use of fibre for the signal transmission to one single detector only.

In this way more bearings and bulkheads can be bypassed and the distance between the sensing points, i.e. between the discs/gearwheels can be made as great as possible in order to increase the accuracy. Fig.3A, 3B and fig.6 show a shaft arrangement with only one bearing (8) bypassed by the optical fibre.

Fig.7 (51) and (52) illustrate two different versions of the discs/gearwheels. The design (52) is an inverted version of (51). The version (51) senses the dark pulses. The version (52) senses the bright pulses. Principally both méthodes can be used. The displayed series of light/dark pulses which hit the light sensitive detector after having passed the two disc/gearwheel coders (51A), (51B) or (52A), (52B) respectively, are indicated as A1,B1.....A12,B12. The number of vanes/teeth on the coding discs shown are 12 and as a result the pulsetrain A1.....B12 corresponds to one turn of the shaft. The circle (53) indicates a possible place for mounting of the lightsource. As already described the spacings between the pulses A1, B1 etc. express the torsion and accordingly the torque of the rotating shaft.

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CLAIMS

1. Apparatus for measuring the torque of rotating shafts by measuring the pulse width generated by two vanes characterised by measuring the torsional angle by means of a narrow lightbeam (2) which is being pulsed by the said vanes (3a,3b), and which are mounted to the shaft (4) at a suitable distance from each other, and that all information on the said torsional angle are in a series signal of width modulated light pulses which are received by a light sensitive electronic detector producing electronic signals in a form that can be stored in a computer memory in order to be processed and that the torque of the shaft can be displayed on a monitor.
2. Measurement of the torque of rotating shafts according to claim 1 and characterised by transmitting the light from the source (1) and through an optical fibre (9) enabling the light to bypass obstructions like shaft bearings (8), bulkheads etc.
3. Measurement of the torque of rotating shafts according to the claims 1 and 2 characterised by using coding discs or wheelgears (16,21) containing a large number of teeth resulting in a large number of light pulses (34,35) each turn of the shaft and that the sum (36) of the light pulses (34,35) contains all the information that are transmitted through the fibre (23) to the receiver (12) which contains one single light sensitive detector that transfer the light pulses into electronic pulses in order to measure the time between the rising edges and the time between the falling edges respectively for the purpose of calculating the torsional angle and consequently the torque.
4. Measurement of the torque of rotating shafts according to the claims 1, 2 and 3 characterised by the method of transmitting light through optical fibres across two air gaps (26,30) with coding discs/gearwheels (16a,21a) mounted to the shaft in suitable distance from each other and that the lightbeams are pulsed in the air gaps after which the light pulses are summed in the light collector (32) and then transmitted by the fibre (33) to a light sensitive electronic detector (12).



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5. Measurement of the torque of rotating shafts according to the claims 1, 2, 3 and 4 and characterised by a method using optical sensors formed as u-profiles (39,40) that receive constant light through the fibres (24a,24b) and retransmit the light in a narrow beam across the airgaps of the u-profiles (39,40) in which the beams are pulsed by the rotating discs/gearwheels (16) and (21) and whereafter the pulsed lightbeams are transmitted through the fibres (28a) and (28b) and added in the the light collector (32) from which the resulting light pulses are transmitted by the fibre (33) to the light sensitive electronic detector (41) in which the light pulses (36) generate electronic pulses that are transmitted by the datacable (46) to be processed by the electronic counters (47) in which all the information on the torsional angle are stored and further transferred by the duplex communication line (48) to the computer (49) in which the RPM, the torque and the power are calculated and displayed.
6. Measurement of the torque of rotating shafts according to the claims 1 through 5 and characterised by the time displacement between the vanes on the discs (16a,21a) and the resulting generated light pulses with the shape (36) in the fibre (33) through which the pulses are fed to the light sensitive electronic unit (12) and converted to the shape (37) and (38) respectively which said pulse shape (37) is generated by detecting the rising edges of the light pulses and (38) is generated by detecting the falling edges of the light pulses thus generating a double set of electronic width modulated pulses each turn of the shaft with a total number twice the number of vanes on the discs (16a,21a).
7. Measurement of the torque of rotating shafts according to the claims 1 through 6 and characterised by adding and storing both the width modulated pulses generated by the rising edges (37) and the width modulated pulses generated by the falling edges (38) in the computer memory over a selected time or a number of turns of the shaft before averaging the summed time displacements after which the torsional angle are calculated as the RPM of the shaft is known.
8. Measurement of the torque of rotating shafts according to the claims 1 through 7 and characterised by the use of inverted signals in the way that light pulses are replaced by dark pulses and vice versa according to the coding discs (51) and (52) respectively.

