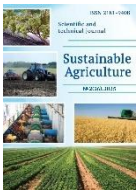
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Elastic Method of Measuring Torque on the Power Take-off Shaft of Rotating Mechanisms

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a r t i c l e i n f o

Keywords:
large pipe, electrode, electric driving force big pipe, Multisim, modele, two phases, bubble.

a b s t r a c t

This article is about the method of capacitive measurement of water consumption in pipes, in which the sensors measuring flow parameters depending on the capacity, pressure and electromagnetic field of the two-phase medium in the pipe are analyzed. Also, in the article, the method of measuring the electric capacity parameter of two-phase current is analyzed in more detail.

1. INTRODUCTION

Torque is one of the main quantities of all rotating mechanisms, and its measurement and control determine the effective operation of various machines. Rotating mechanisms play an important role not only in agricultural machinery, but also in various machines used in industry and even in simple mechanisms.

Methods for measuring the torque of rotating mechanisms are divided into contact and non-contact measurement types according to the connection of the measuring instrument with the rotating mechanisms. Each of these measurement methods is further divided into many types and also depends on the measuring characteristics of the sensor. Currently, torque measuring sensors are divided into 12 types according to their various characteristics.

In particular, various torque sensors such as strain gages, clamps, magnetoelastic, scattered fiber grating, surface acoustic wave, magnetostrictive, magnetic Barkhausen noise, magnetoelectric, photoelastic, photoelectric effect, laser Doppler-based, and laser spot are among them.[1].

According to [1], optical sensors can be divided into 3 types according to their principles, namely interference, laser spot, and laser Doppler. The main idea of these sensors is that when a load is applied to a rotating shaft, its surface lines bend to form a certain angle.

However, when the load is very small, this angle of rotation may not have a significant value. This can reduce the sensitivity of the sensor and increase the measurement error.

Torque measurement is carried out not only for medium and large-sized devices, but also for micro-level mechanisms. This issue is especially relevant in microelectromechanical systems, microelectronics and digital technology. In [2], a photoelastic torque sensor was proposed for measuring the torque of DC micromotors. This sensor uses a silicone elastomer and uses an optical method. When the motor is loaded, the light intensity at the output of the silicone material changes. The measurement principle is based on this principle.

Torque measurement is necessary not only on the ground but also in space for automatic control of manipulators operating outside the space cabin and for ensuring the flexible operation of devices. For this purpose, a piezoelectric 6-dimensional force/torque sensor measuring force and torque in 3 axes has been developed [3]. The principle of operation of the sensor is to analyze the signals received from 8 piezoelectric elements mounted on a circular ring.

In this sensor, if 2 of the 8 elements fail, the signal amplitudes of all the remaining elements will decrease. This will lead to an increase in the total measurement error.

In most cases, the torque on the tractor power take-off shaft is measured using a strain gauge bridge circuit [4]. When a torque is generated on the shaft, the balance of the strain gauge bridge is disturbed. The signal at its output is transmitted to the measurement and control system in a non-contact manner, and this signal is processed and analyzed. Also, in this literature, the forward speed of the tractor wheel is measured using a Hall sensor [4].

The deflection of the tractor power take-off shaft under the influence of a torque is also directly dependent on the material of the shaft. At small loads, this deflection is almost imperceptible. This requires very high measurement sensitivity of the measuring sensors.

There are also sensors using amorphous magnetostrictive tapes for torque measurement [5]. In it, two tape strips are made at 450 relative to the shaft and are glued to the shaft. There are two pulleys connected to these two tapes without contact. The two pulleys are part of a multivibrator bridge circuit. When the shaft rotates, the magnetic field of the pulleys changes and it directly affects the output parameters of the multivibrator. If a torque appears on the shaft, then a difference occurs between the zebra tapes.

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The magnetic properties of the tapes decrease with temperature. This is a factor that affects the sensitivity and measurement error of the sensor. Capacitive sensors can also be used to detect torque on rotating shafts. Such a sensor [6] consists of parts such as a stator and a rotor, each of which is made in the form of teeth with a specific structure. When torque is applied to the shaft, the angle between the stator and rotor patterns changes, and this phenomenon leads to a change in the capacitance between them. The output voltage of the sensor also changes proportionally to the change in capacitance.

However, in such sensors, extremely high accuracy requirements must be imposed on the size of the stator and rotor gap, otherwise the measurement error will increase. Ensuring such accuracy requirements is a rather complex research task. Surface acoustic waves are similar to longitudinal seismic waves. They affect solid bodies only to a depth of the order of the wavelength. They are slightly attenuated when moving forward on the surface, and in solid bodies the motion of particles is elliptical. If an external quantity affects the propagation properties of the surface acoustic wave of the piezoelectric material, the phase velocity of the surface acoustic waves changes. In this case, the frequency of the SAT (surface acoustic wave) sensor also changes. By measuring this frequency, the user can determine indirect measurements of the parameter under observation.

Torque sensors operating on the same principle are given in [7], which can also monitor the temperature of the shaft at the same time.

However, the structure of these sensors is complex and the measurement error increases during vibrations.

The next sensor, consisting of a piezoelectric sensor, an electromagnetic coil and a permanent magnet, is a new method for measuring the torque of rotating mechanisms [8]. According to it, when a torque appears on the shaft, the distance between the radially arranged permanent magnet and the electromagnet changes. This distance is adjusted by adjusting the electromagnetic field strength. Therefore, the torque on the shaft is directly proportional to the resistance force of the electromagnet. The accuracy of the measurement result is assessed using a piezoelectric sensor.

One of the main characteristics of an electromagnet is the nonlinearity of its static characteristics [9], and the sensitivity of the permanent magnet to temperature leads to a number of errors.

A differential transformer sensor is also available, consisting of two stator windings on either side of the shaft and a concentric cylinder [10]. Each cylinder has a series of splines that rotate with the shaft. When torque is applied, the splines overlap, and a voltage proportional to the torque is generated. One of the main disadvantages of this sensor is that errors increase at high speeds. In [11], torque and angular velocity measurements are used to calculate tractor power. This device is similar to a car's disc brake system. In it, an artificial load is applied to the power take-off shaft and the torque and angular velocity of the shaft are measured. The power is calculated using the following formula:

$$P=2\pi NT/60000$$

where, is the rotational speed of the N-shaft (m/s); T-moment(N·m).

However, this device cannot be used during tractor operation, because its dimensions are large, and the braking and stopping process is dangerous. In recent years, optical methods for measuring torque have been further developed. A clear example of this is the non-contact measuring sensor for determining the torque of rotating mechanisms. This sensor consists of a zebra tape attached to the shaft at a distance x from each other and optical sensors mounted on fixed rigid supports[12]. Torque measurement consists of analyzing the signals received from the zebra tape of the optical sensors. When torque is applied to the shaft, a difference or shift appears between the two sensor signals. There is a relationship between this shift and the rotating torque as follows[12]:

$$T = I\ddot{\theta} + C\dot{\theta} + K\theta \ ,$$

where, I is the moment of inertia of the rotating system, S is the damping coefficient of the mechanical vibration of the shaft, K is the torsional stiffness of the shaft, θ is the relative rotation of the shaft ends, and T is the torque.

When a shaft is subjected to a torque, the torque must be greater for the shaft to rotate, or the distance between the optical sensors to measure the torque in this way must be increased. This creates inconveniences during the operation of tractors.

The proposed sensor for determining the absolute torque on the shaft operates on a special principle. It converts the torque acting on the shaft into a displacement along the horizontal axis. For this purpose, this sensor uses rings with uneven surfaces, steel balls, a proximity sensor, and devices that record horizontal displacement [13].

The biggest difficulty in this sensor is the friction force, which increases when converting the rotational force into horizontal motion. This can lead to system failure at high accelerations.

The measurement method using resistances and capacitances is divided into 3 types. 1- torque measurement based on resistance and capacitance changes; 2- bridge circuit based on resistance deformation and 3- capacitance torque measurement based on phase difference. This requires capacitance meters consisting of resistances mounted on the shaft at 450 degrees to each other, fixed and movable parts [14].

However, these methods require a significant influence of the external environment on the capacitance and a constant distance between the fixed and moving parts.

The torque clamp method consists of 4 rods mounted parallel to the shaft circumference, which are in turn fixed by opposing collars to form a bridge circuit. When a torque is generated on the shaft, the balance of the bridge is disturbed [15].

The main disadvantage of this method is that the rods take up a large amount of space on the shaft and are sensitive to temperature.

In the method of measuring torque using fiber Bragg gratings, the device is made in the form of a spring, and data on deformation, bending, and compression in different directions are obtained through 8 sensors. Based on this data, the value of the shaft's torque is determined [16].

However, the complexity of the design and the high cost of the elements limit the possibilities of using this method.

There is also a method called the Barhausen noise method, which is based on measuring the noise similar to the signal induced by the magnetic field applied to the ferromagnetic material [17]. This method requires that the temperature not be high, and for this reason, its use is always limited.

The photoelectric method is of great importance in measuring the power of rotating mechanisms. This system consists of a light source, a photodetector, an elastic element, and analyzing parts. Its operation is based on a decrease or increase in light intensity due to a change in the position of the elastic element when a torque appears on the shaft. The system summarizes data obtained from horizontal and vertical sensors [18].

Since air pollution is often observed in field conditions, the use of this method leads to errors.

One of the modern methods for measuring torque on a shaft is the magnetoelastic method. Its principle of operation is to analyze changes in the magnetic field [19].

The main disadvantages of the sensor are the incorrect selection of the shaft material during design and the inability to determine the direction of the torque.

Based on the analysis of the above data, the methods for measuring the torque of rotating mechanisms can be classified as follows. This classification is presented in Figure 1 below.

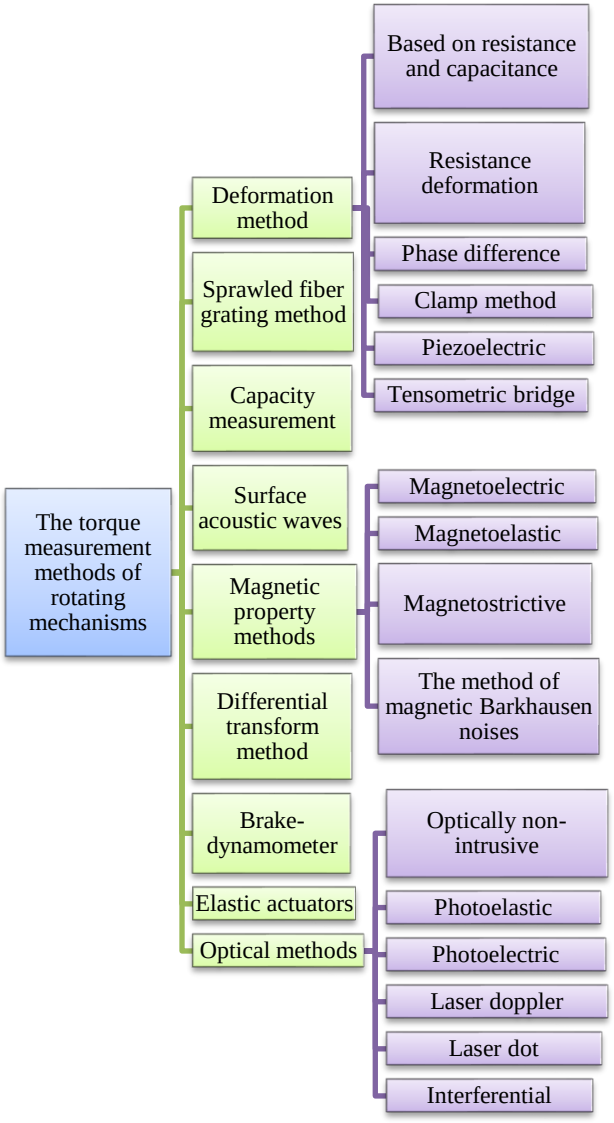


Figure 1. Classification of torque measuring sensors for rotating mechanisms.

Figure 2 shows a comparative diagram of the torque measuring sensors of rotating mechanisms. It can be seen from the diagram that the measurement accuracy of the differential transformer sensor is higher than that of other sensors. The accuracy of optical and piezoelectric sensors is the same, and magnetoelectric sensors occupy the last place in this regard [21].

Optical sensors are the leaders in terms of the width of the measurement range (Figure 3).

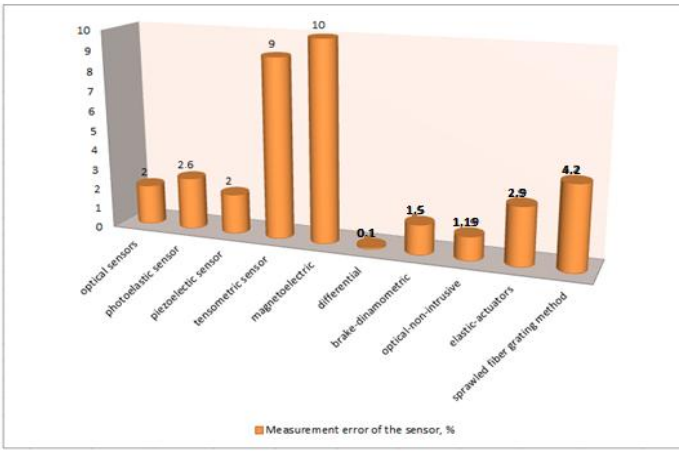


Figure 2. Comparative diagram of measurement errors of torque measuring sensors for rotating mechanisms.

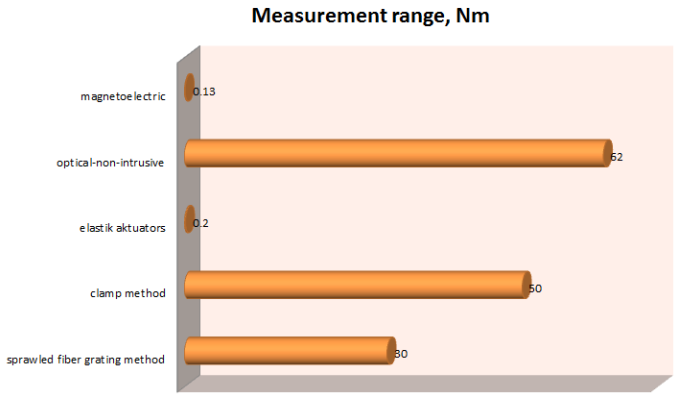
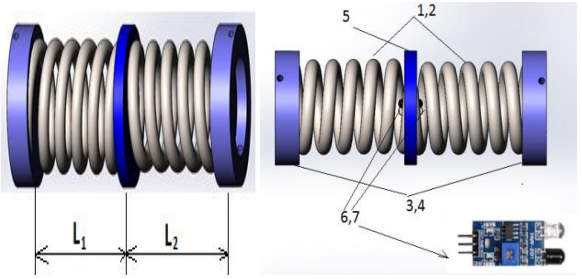


Figure 3. Upper measurement limits of torque sensors

2. MATERIALS AND METHODS

A sensor based on spring elasticity has been developed to measure the torque of rotating mechanisms (Figure 4). Its measuring chain consists of the following parts: 1,2- oppositely rotating springs; 3,4- clamping discs; 5- intermediate disc; 6,7- proximity sensors, microcontroller.



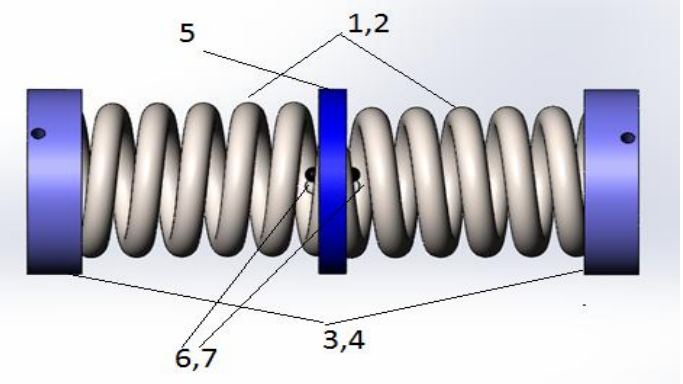


Figure 4. Method for elastic measurement of torque of rotating mechanisms.

In this case, the microcontroller considers the following conditions:

L_1>L_2 In this case, the shaft moves clockwise and there is a torque on the shaft.

L_1<L_2 In this case, the shaft rotates counterclockwise and there is also a torque.

L_1=L_2 The position of the springs is unchanged. In this case, the amount of load on the shaft is small, so the amount of torque is zero.

L_1=L_2 Both springs are in a state of compression or extension. In this case, the shaft is under axial forces and the torque is zero. In this case, the sensor measures the amount of pulling or pushing force.

The microcontroller processes the received data and transmits the result to the display.

We use an infrared proximity sensor module to measure the change in the distance between the disks (Figure 5).



Figure 5. Infrared proximity sensor.

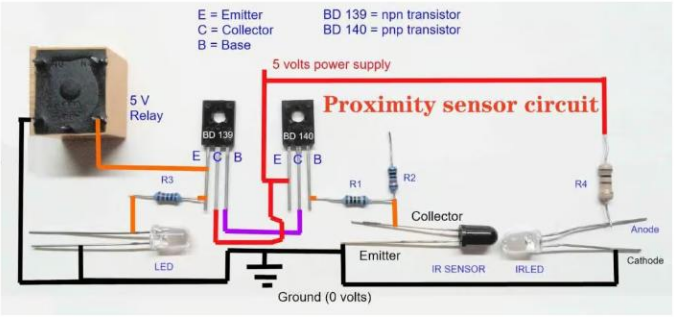
The sensor parameters are given in the table below.

Table 1. Proximity sensor parameters

Infraqizil Proximity Sensor Moduli
• Detection distance: 2 ~ 30 sm
• Detection angle: 35 °
• Comparison chip: LM393
• 3mm screw holes for easy installation

3. DISCUSSION.

The proximity sensor measurement circuit consists of BD 139, BD 140 transistors, a 5V relay, resistors, an IR LED, and an IR sensor (Figure 6).



The following ratios are used to calculate springs. Pitch of a cylindrical spring with a round cross-section[

$$t = \pi(D-d)\,\mathrm{tg}\,\alpha$$

where α is the angle of elevation of the coils (α=5^0÷〖15〗^0, often 6^0÷〖49〗^0 is taken). D is the surface diameter of the spring, d is the diameter of the spring wire. The length of the stretched spring[19]:

For compression springs:

$$L = \frac{\pi(D-d)n}{\cos\alpha}$$

For extension and torsion springs:

$$L = \frac{\pi(D-d)n}{\cos\alpha}\cdot L_{u.y}$$

$L_{u.y} -$ *is the length of the loop wire. n is the number of turns.*

The length of the spring is found as follows for the case where the support surfaces are smooth:

$$L_0 = n(t-d) + (n_1 - 0.5)d$$

The length of the spring for unpolished bearing surfaces

L_0=n(t-d)+n_1 d

Here, n_1 is the number of complete packages.

Using formula (3), we can write expression (7) as follows:

$L_0 = n(\pi(D-d)tg\alpha - d) + n_1 d$

Here n_1=n+1.5 Considering that, then

$$L_0 = n\pi(D-d)tg\alpha + 1.5d$$

we will have an expression.

4. RESEARCH RESULTS.

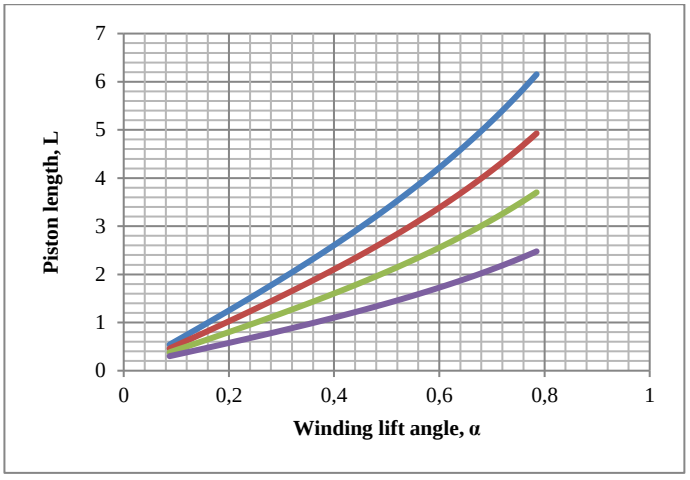


Figure 7. Variation in spring length for different diameters of spring wire.

Figure 7 above shows a graph of the dependence of the spring length on the angle of elevation of the coils.

We determine the cross-sectional moment of resistance of the coil of the spring from the following expression:

$$\boldsymbol{W_p = \frac{\pi d^3}{16}}$$

Below is a graph of the change in the moment of resistance

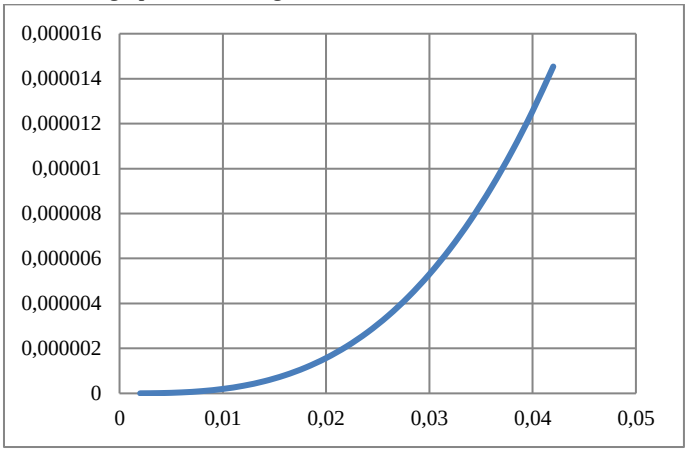


Figure 8. Graph of the change in the moment of resistance.

In this case, since the spring is connected to a rotating shaft, we equate the torque acting on the shaft to the torque of the spring:

$$\boldsymbol{M_b = M_{pr}}$$

The spring moment is found by the following formula:

$$M_pr = k\cdot\theta$$

where k is the torsional stiffness of the spring; θ is the angle of torsion.

Torsional stiffness of the spring

$$\boldsymbol{k = \frac{G\cdot J}{L}}$$

Substituting formula (13) into (12), we obtain the following

$$\boldsymbol{\theta = \frac{M_{pr}\cdot L}{G\cdot J}}$$

where J is the moment of stiffness of the spring, which is calculated as:

$$J = \frac{\pi R^4}{2}$$

where R is the radius of the spring.

The deformation of a spring is directly proportional to its radius and the angle of rotation.

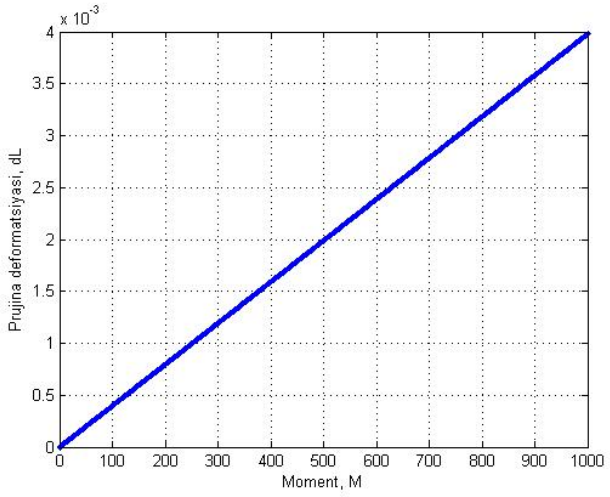
$$\Delta L = R \cdot \theta$$

If we generalize the last three formulas, we get an expression for the dependence of the torque on the spring deformation.

$$\Delta L = \frac{2 \cdot L}{G \cdot \pi \cdot R^3} \cdot M_b$$

G- is the shear modulus, which is usually 8· 〖10〗 ^10 Pa for steel. L-The length of the spring.

Below is a graph of spring deformation versus torque.



9-rasm. Prujina deformatsiyasining o'zgarish grafigi.

5. CONCLUSION:

The following conclusions can be drawn from this work:

Deformation, magnetic and optical methods make up a large part of the torque measurement of rotating mechanisms.

While optical methods are the leader in terms of the measurement range, differential transformer sensors are superior in terms of measurement accuracy.

The advantages of measuring the torque of rotating mechanisms using spring deformation and proximity sensors are the simplicity of the design and the ability to adjust the measurement range.

Temperature, humidity, dust particles, and electromagnetic interference can be taken as factors affecting the output magnitude of the torque sensor. An increase in temperature leads to an increase in deformation and the output voltage of the proximity sensor. If humidity also affects the proximity sensor like temperature, dust particles reduce the light intensity and lead to errors.

Electromagnetic interference serves as an additional source of noise, and electrical filters are used to eliminate its effect.

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