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Grzegorz Mirek*, Grzegorz Lenda*, Rafał Kocierz*

Hallotron Sensor System for Control of Robotized Total Station Operations to Monitor Movements of Building Structures

1. Introduction

Developments of electronic components in response to movement inducing phenomena allow to design better and more precise sensors able to determine relative movements of any object or its part.

At the same time there are commercially available robotized total station with an option of automatic target recognition (ATR), able to automatically measure the series of directions set on the object. Those objects may include a bridge, dam crowns and other extended or surface engineering structures which require periodical inspection during the erection stage as well as during their proper maintenance and operation.

There are load tests to be conducted upon completion of those engineering structures, in order to confirm the stability of structures, and therefore their safety. It applies to both inspection of the object component relative displacements as well as to its absolute position in space as referenced to selected points of the control network.

Appropriate measurements are conducted independently, with use of dedicated sensor sets on one hand, and by observations carried out with conventional geodetic instruments on the other.

While the monitoring of relative displacements by means of sensors could be carried out continuously, relative geodetic measurements are usually conducted independently, according to a set schedules.

The subject of this paper refers the automatic control of absolute measurements done by means of sensor sets placed on the inspected object.

* Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, Krakow

2. General Concept of System Design

The offered system is based on hallotron sensors of relative displacements, able to control the robot tachymeters. Any runout from a set value of displacement for a given sensor causes automatic release of series of measurements to be conducted for predetermined directions. For that reason all absolute measurements are done as a direct result of real changes that existed within an object. This will enable to draw more realistic evaluation of existing displacements in comparison with absolute observations conducted independently.

General diagram of system operation is shown in figure 1. The system components discussed in detail in accordance to this diagram are: hallotron system of sensors providing displacement information, electronic detection system of displacement threshold value, as well as software module controlling the total station operation.

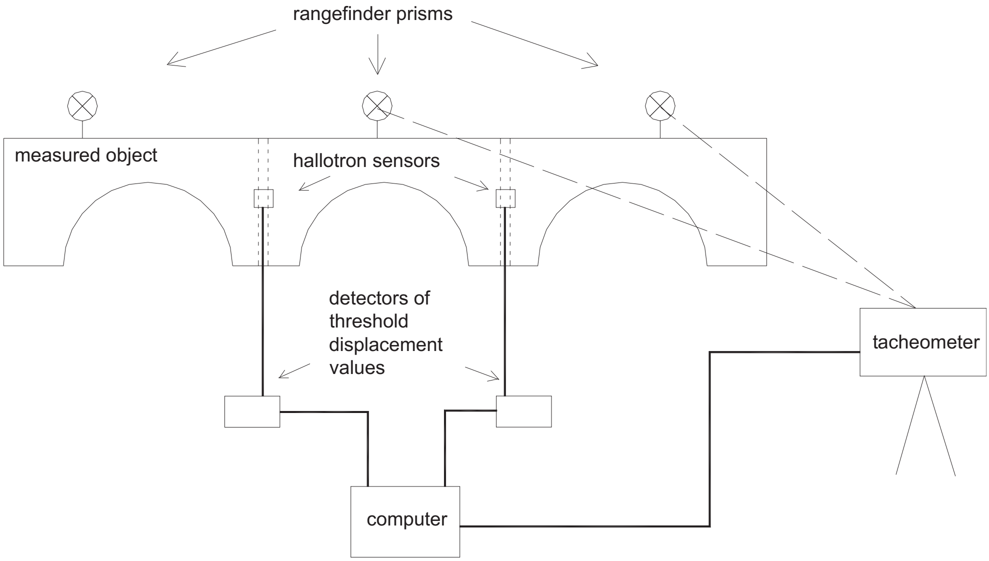

Fig. 1. General diagram of robotized total station control system with a use of hallotron sensors

2.1. System of Hallotron Sensors

A fundamental designation of sensors is to react properly to existing displacement. A few types of sensors were chosen for the presented system in order to make various detections of positional changes in the object or its parts possible. Those sensors are designated to detect the observed object displacement, inclination or vibrations. Detection will be carried out with linear hallotrons, operating in various configurations together with magnets.

The main components of displacement sensor include linear hallotron (Fig. 2) and a permanent magnet which is a source of strong magnetic field. Change of distance between magnet and hallotron causes an instant change of voltage resulting from deviation of current carriers flowing through the hallotron induced by the Lorentz force [3]. A parallel displacement of magnet along hallotron has a similar effect on both components positioned at a constant distance with each other. The mentioned potential difference, also known as the Hall voltage, generates the sensor output voltage signal upon suitable amplification.

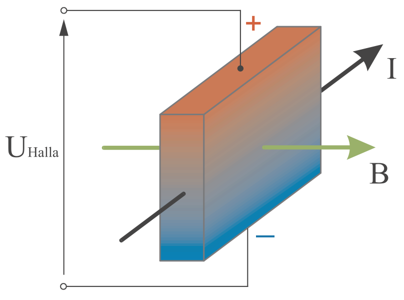

Fig. 2. Hall effect. *UHall* – Hall voltage, *B* – magnetic induction, I – current flowing through hallotron semi-conducting plate

The sensor is designed based on integrated circuit A3515, and its electrical circuit diagram is presented in figure 3. Value of low level output signal depends on hallotron power supply voltage. Thus, in order to desensitize the sensor to power supply voltage fluctuations, a voltage regulator (integrated circuit L7805) [7] was added to the system.

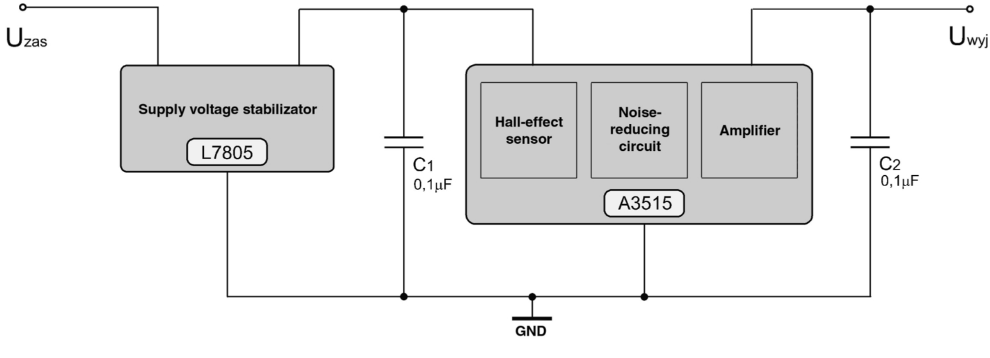

Fig. 3. Electric circuit diagram of hallotron sensor. U_{zas} – supply voltage, U_{wyj} – output signal, C_1, C_2 – capacitors rated at 0.1 F

As a result, value of displacement X monitored by the above mentioned sensor is a function of its output signal, according to the following formula:

$$\Delta X = F_H(\Delta U_{wyj}) \tag{5.3}$$

where U_{wyj} – output signal, in V.

Function graph *FH* (hereinafter called a sensor response), depends not only on intensity of the magnetic field, but also on location of hallotron (or its configuration), in relation to one or more magnets (Fig. 4). Taking into consideration that a sensor should detect determined threshold value of displacement or inclination which may be a product of several components, it was necessary to analyze various particular sensor configurations. Knowledge of output signal response method to existing displacement will allow to determine the threshold level and generate a pulse which would initiate series of control measurements taken with precision geodetic instrument, when such borderline is exceeded.

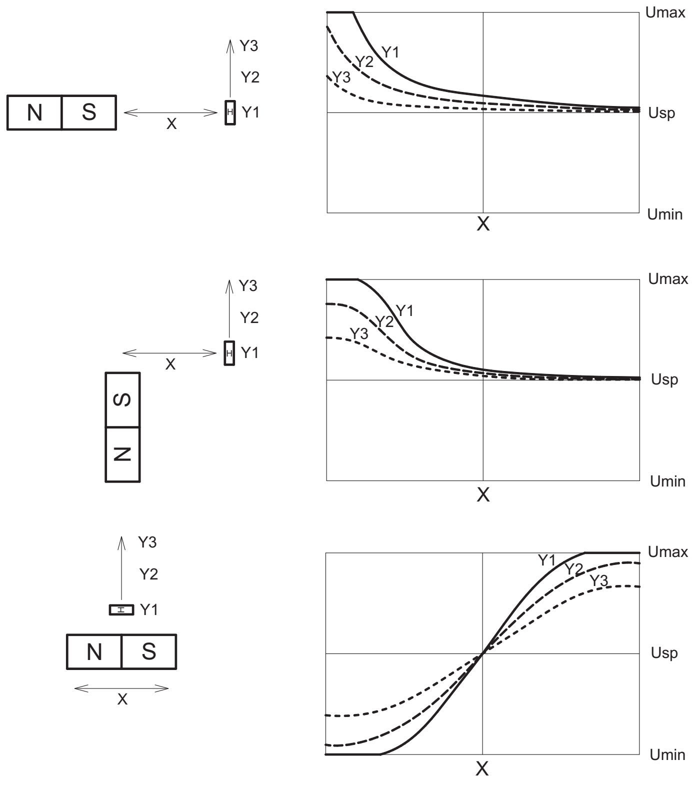

Fig. 4. Configurations of hallotron sensors and method of reaction to existing displacements. Shown are: axial configuration, transverse configuration, parallel configuration

Taking into consideration the above responses, separate sensors were designed for detection of displacements, inclinations and vibrations to be used in the proposed system. A parallel configuration sensor was applied, due to its simplicity as well as sensitivity and linearity in mid section of its response graph, for detection of displacements taking place, i.e. in expansion joints. The linearity is in particular to the sensor advantage within this configuration, since voltage appearing on components terminals can be easily converted to the present displacement. As a result it is relatively easy to determine a borderline that initiates a tacheometric measurement after appropriate displacement thresholds are exceeded. A single sensor can only control the displacement in one direction, therefore it is necessary to install pairs of sensors perpendicular to each other, since they enable to detect the relative displacements of structural components taking place both along and across the expansion joint (Fig. 5a).

Installation of sensor with a ring magnet suspended centrally over the hallotron was carried out in order to detect inclinations of the structural components. In this case it is also a transverse configuration in the event it is cut with any vertical plane. Due to particular shape of the magnet, a single sensor is sufficient to detect inclinations taking place in all possible directions. While the less advantageous response graph is being generated when compared with a parallel configuration, it was necessary to select the magnet ring diameter in such way that the operating range of the sensor is allocated within the steepest portion of the response characteristics, while using possibly shortest arm of the pendulum.

This sensor may also function as a vibration detector when suitable threshold values are selected (Fig. 5b). Generation of vibrations within the structure would initiate a tacheometric measurement after the set value of amplitude is exceeded.

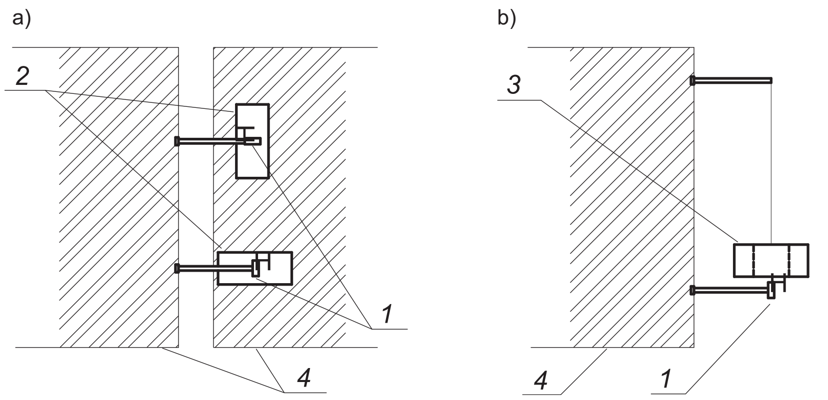

Fig. 5. System sensors: a) detection of relative displacements; b) detection of inclinations and vibrations; 1 – hallotrons, 2 – plate magnets, 3 – ring magnet, 4 – inspected structural components

2.2. Detection of Displacement Thresholds

A basic designation of sensors is to convert a displacement of magnet (or its standing off) in relation to hallotron, into a measurable electric signal. Exceeding of preset defined signal value will effect in a release of series of the measurements carried out by a robot tachymeter. The proposed system will therefore have to be equipped with the calibrated voltage standard sources corresponding to displacement value which initiates the total station. Those sources will provide information pertaining to runout from a threshold value, by comparing it with a generated signal.

Apart from the sensors, an integral part of the system includes also circuits which compare sensor outputs with preset threshold values represented by reference voltage levels U_{ref}. Those circuits should then respond both to situation when the predefined voltage value is exceeded and allow to adjust it automatically in steps. It should therefore be assumed that the proposed system will operate continuously, responding appropriately to changes appearing in time within the object. Increased or decreased deformations will be accompanied by sequential changes of voltage threshold values which release a tachymetric measurement. The task for a user will therefore be to determine the initial threshold value of displacement as well as distances between the following threshold values. A knowledge of sensor response graph is needed to perform such task for sensors operating in selected configurations. To determine the sensor responses they have to calibrated before hand, and their responses F_H approximated, based on discreet test measurement results. Due to little complexity of the response graphs (Fig. 4), one could use low degree polynomials or, with even better results, make use of spline functions. By having F_H, it is easy to determine voltage value U_{ref} corresponding to assumed limiting value of displacement.

Method of total station control by means of sensors operating with variable threshold displacement detectors is presented in figure 6.

Hallotron sensor converts a magnitude of magnet position change into electrical voltage. Its initial threshold value to initiate the tachymeter (determined based on sensor response) is set by the voltage regulators upon activation of power supply. It is necessary to use two systems (comparators) comparing voltage with a standard voltage value. Naturally, parallel displacement may occur in a positive or negative direction in relation to accepted zero value level. Similarly, during detection of inclinations or vibrations, the magnet may get closer to hallotron or move away from it, this generating sensor voltage increases or drops. In order to ensure proper operation of threshold value runout detectors it is necessary to determine reference voltage for both upper and lower initial threshold values. Exceeding of any of those values will result in change of logical state of the XOR gate output, and that is registered at the input of PC serial port. At this very moment the computer will start a program designated to control automatically the measurement of predefined series of directions towards rangefinder prisms located on the object.

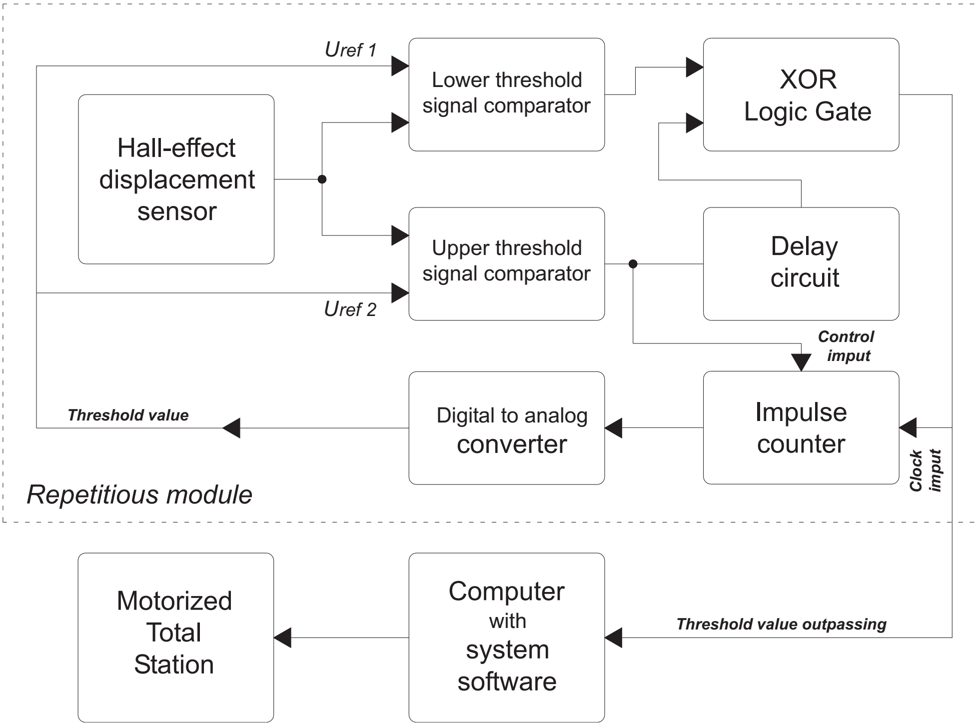

Fig. 6. Block diagram of hallotron system for robotized total station operation control

However, the described system would operate only once, since these exceeded voltage threshold values are not going to vary. As it is explained above, system incremental response to the magnet position varying in time requires a change of reference voltage levels. Therefore control of the voltage U_{ref} was solved by application of a counter fired by pulses originated in comparators and adding up the number of times threshold was exceeded. That number is then converted to analog form by means of suitably calibrated digital/analog transducer and used as a reference voltage for detection of the next threshold runout pertaining to a current position of the magnet. Applied counter must be able to increase and decrease its readout, depending whether it was the upper threshold value, or lower threshold that was exceeded. This will correspond to increase or decrease of voltages controlling the comparator operations. Value by which the upper (lower) threshold was exceeded must result in incremental, identical increase (decrease) of U_{ref} for both upper and lower threshold values. This is related to possibility of a displacement occurring at any time, in the direction opposite to the last one. Shifting of the whole range, with boundaries limited by equally modified threshold values U_{ref}, will allow to register those changes.

A binary 4029 counter [2] capable of decimal counting up to ten or binary up to sixteen may be used here successfully. This counter is also capable of changing the direction of counting, depending on the logic status at its controlling input (low signal – reverse counting, high signal – forward counting). Method to control this counter is illustrated in figure 6. Should the lower threshold value U_{ref} be exceeded, a high signal appears at the counter clocking input. At the same time, a low signal from comparator recording a high threshold value U_{ref} is fed to the input controlling the direction of count. This causes the counter to start counting in reverse, and that will be converted by digital to analog converter to decrease threshold values U_{ref} by a preset increment. If, in turn, an upper threshold value U_{ref} is exceeded, a high signal will be fed to the controlling input and the counter switches direction of count (to forward direction). Switching of the counter must take place before high signal appears at the counter clocking input. For this reason time delay circuit was used before XOR gate input for the upper threshold value.

Shifting of threshold value U_{ref} ranges up or down will cause switching of comparator output to low signal, and in these circumstances the system will wait for a displacement exceeding currently preset threshold values of U_{ref}.

2.3. Controlling Total Station from a Computer

A short pulse at the output of XOR gate appears and fades out upon setting new threshold values U_{ref} during the system operation at the very moment when a current threshold value U_{ref} is exceeded. This is used to control robot-tachymeter from a personal computer.

A serial RS232C standard was selected for communication of sensors with the computer. Since sensor outputs the signal only in case the displacement threshold value is exceeded, then there is a possibility to use four signal lines for each of the serial ports installed within the system:

- CTS (Clear To Send),
- DSR (Data Set Ready),
- RLSD – DCD (Data Carrier Detect),
- RI (Ring Indicator).

Logic status of binary 1 corresponds to the range between +3 V to +25 V in those lines; and this is described as “high” or “on” condition. At the same time, a logic status of binary 0 corresponds to –3 V to –25 V value. When the hallotron sensor detects a displacement, it sends a +10 V short pulse through one of the selected lines. The software installed on the computer systematically monitors conditions of particular lines controlling the defined ports, and in case of recording the high condition saves it in the database.

Taking into consideration the result interpretations, it would be most convenient if each sensor was connected to a separate line. If this was the case, then the control program (as well as the user) will be able to recognize the location of displacement on the object. However, this solution is not very practical, since the computer would have to be equipped with installation of 4 serial ports (i.e. USB-R232C converters) to take care of 15 sensors. The problem can be solved through cascade connections of OR gates with their inputs connected to the outputs of XOR gates with the last row (Fig. 6). However, in this case we lose information pertaining to location of the sensor that recorded a particular displacement.

The program analyzes previously defined entries in the database simultaneously with analysis of the signals from hallotron sensors. If one of the sensors is exposed to displacement, the program should respond to that in accurately defined way. Typical events that may take place in those situations include sending e-mail message to the person responsible for the structural object safety or a carrying out a precision geodetic measurement, thus making it possible to determine the magnitude of displacement in a closely defined reference system (absolute displacements). It should be noted that the signals from various sensors may reach the computer within very short time ranges. This could be caused by almost simultaneous response made by a few sensors, or a quick release of output signal from a single sensor, due to appearance of a larger displacement. In such case, repeating signals appearing within RS232C port lines would continuously initiate the measuring system which was already previously activated.

In order to resolve the above mentioned problem, one can choose one of two possible accepted solutions of the control software:

1. Tacheometric measurement is initiated at the very moment of displacement detection. Upon completion of measurement the system checks if any other displacements took place since the beginning of measurement initiation, and if this is the case, it restarts geodetic measurement procedure.
2. Upon getting the displacement signal the system holds it for a predetermined period of time (i.e. 5 minutes), and if no more signals appear from hallotron sensors, then the tachymetric measurement is activated. In the event new readouts appear, indicating that the monitored object is still moving, the system waits for its stabilization and then initiates observations with a use of robotized total station.

When designing a whole monitoring system, one should ask a question what type of tachymeters are used and how can they be controlled. In the system described here these sensors control Leica tachymeters which basically meet the requirements for accuracy, quality and offer broad possibilities for remote control of their operation.

Communication of the measuring instrument with computer is established using a RS232C standard. Since only a few computers are now equipped with this standard (or do not have a sufficient number of those ports), one could use suitable USB-RS232C converters or wireless Bluetooth transmissions. Upon setting transmission parameters (same for both computer and the instrument), it is possible to open a selected port and send program commands to control operation of the total station. Each manufacturer developed their own set of commands (language) to control the instruments. For their older generation of instruments Leica introduced GSI OnLine [6] standard, while in case of the robotized instruments it is necessary to use a newer GeoCOM [4, 5] protocol. It is based on RPC (Remote Procedure Call) protocol developed by SUN Microsystem [5]. It has been implemented as a "point to point" system, wherein the client (computer) is located on one side, and the server (total station) is placed on the other side. Transmission of commands and responses is carried out in a synchronous mode, therefore a new inquiry can only be transmitted upon getting a response to the one previously sent. The inquiry syntax may look like shown below:

%R1Q,<RPC>:<P0>, <P1> ….. <Term>

where:

%R1Q – request GeoCOM type 1;
<RPC> – number of remote procedure to be carried out by the instrument;
: – separator between the protocol header and parameters;
<P0>, <P1> …. – possible function parameters;
<Term> – end of line character.

The user obtains the following line of data as a response, with the syntax shown below:

%R1P,<RC_COM>:<RC>, <P0>, <P1> ….. <Term>

where:

%R1P – response GeoCOM type 1;
<RC_COM> – response code signaling successful communication
: – separator between the protocol header and parameters;
<RC> – response code indicating successful completion of remote request;
<P0>, <P1> …. – values of parameters – request results;
<Term> – end of line character.

Upon reaching a suitable combination of commands the instrument is navigated into approximate position of the measured reflector (obtained by earlier measurement or based on coordinates) and then the measurement with using automatic target recognition (ATR) is released. Observed angles and distances for each of predefined points are immediately transmitted to computer, where the data is averaged and recalculated into spatial coordinates in order to determine absolute displacements.

3. Conclusion

The system presented in the paper, distinguished by the time coordination of precision, absolute measurements with simultaneously occurring relative displacements, may find application within the scope of operation/maintenance measurements in broad range of engineering structures. Further development of the above mentioned system will be concentrated on refining the sensors, in order to enable not only a detection of relative displacements, but also their precise measurements.

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