Capacitive Sensor for Rotational Seismology

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Abstract**-**Studying of rotational components of ground movements belong among emerging approaches in recent geophysics. Rotations can be observed using the dense seismic arrays (micro-arrays, small aperture arrays) formed from classic three-dimensional seismic sensors. The aim of this project is a construction of portable, high-definition sensor of rotational movement around vertical axis. This sensor is based on measuring of changes of capacitance of differential capacitor.

I. Introduction

The rotation components of seismic ground motion can be radiated from the source or can be generated when seismic waves spread through anisotropic (micromorphic) rock massif or rise as the response of building structures on dilatational excitation. The rotation component of strong ground motion can represent a non-negligible contribution to the whole earthquake hazard to building structures in near zones. The excitation of rotation vibration depends on the structure of subsoil, on the dynamic response of building structures and on build-in components. This holds especially for building constructions with prevailing linear shape, such as pipelines and rapid rail lines and for objects with great seismic risk (e.g. nuclear power plants), great seismic vulnerability and for historical buildings.

Actually there is no mobile seismic sensor of such kind of motion. Rotational movements are evaluated from signals of classic three-dimensional seismic sensors in dense-arrays [1]. There is only one permanent station for measuring rotational movements – in Germany. It is based on laser interferometer [2].

II. Methods

The angular deflections of a rotation seismometer have very small amplitudes (from nanoradians to microradians) at long periods of teleseismic events. Therefore the deflection-to-voltage transducer must be extremely sensitive especially for long periods of motion.

Our sensor of this kind of movement is realized as a differential capacitor in shape of one twelfth of roundel (fig. 1). It is mounted on a long arm fixed by balancer in stabilized position. The balance wheel hangs on a straight spring realizing the sensor of rotation around the vertical axis. Its natural oscillations are damped electro-magnetically using strong permanent magnets and cooper lamellas at the opposite side of the arm. The first idea was to build as large capacitor as one third (120-degree arc) of disc is but we hit the limit of the manufacturing technology. Maximal size of board in required accuracy (10^{-1} mm) is 500 mm × 250 mm.

Active parts of capacitor are three desks (fig. 1) with electrodes made by technology of printed board circuits (PCB). Two desks are fixed as stators and one is moveable around vertical axis (rotor). Differential capacity is not depending on the distance between the inner and outer board. Therefore it is possible to leave out the vertical movements. Electrodes are designed as sectors (radial rays) with half horizontal covering (fig. 2).

Capacitance between each static desk and the rotational one increases or decreases depending on the sense of the rotation. These changes in order of femto-Farads (fF), are monitored by a sensitive capacity bridge.

The area of whole capacitor can be calculated by (1).

$$S_{el} = N \cdot \varphi_{el} \cdot \left(r_{out}^2 - r_{in}^2\right) \tag{1}$$

Where N is number of rays, φ_{el} is angle of electrode arc, r_{out} and r_{in} are outer and inner radius.

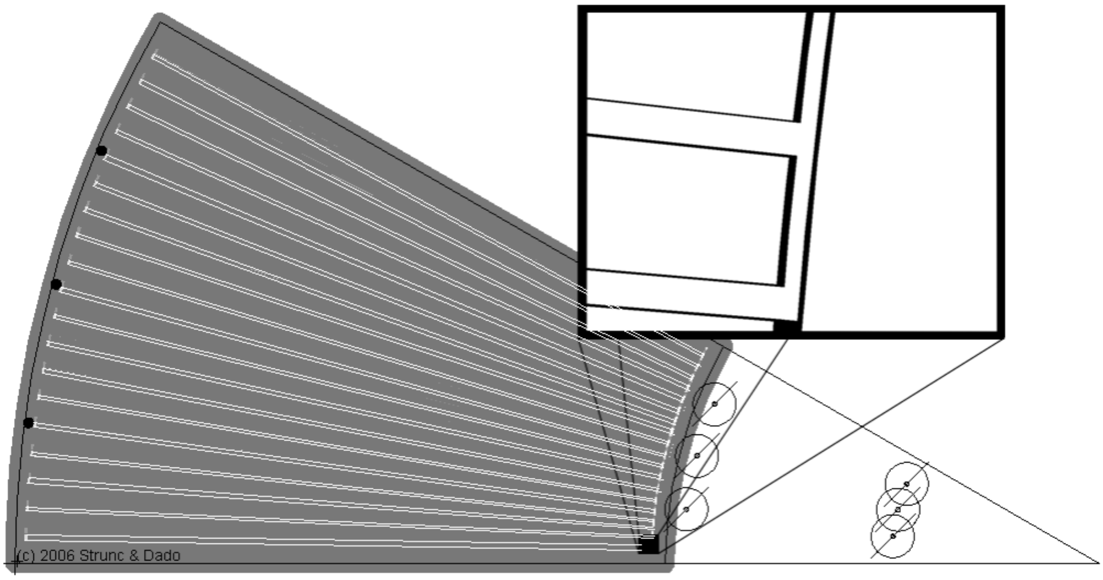

Figure 1. Board with zoomed electrodes

Final capacitance of the sensor is (2).

$$C = \varepsilon_0 \cdot \varepsilon_r \cdot \frac{N}{d} \cdot \varphi_{el} \cdot \left(r_{out}^2 - r_{in}^2\right) \quad (2)$$

Where d is desk spacing, ε_0 and ε_r are the permittivity of vacuum and the relative permittivity of air. Differential capacitor does not depend on the position of the middle electrode when the outlying ones are static.

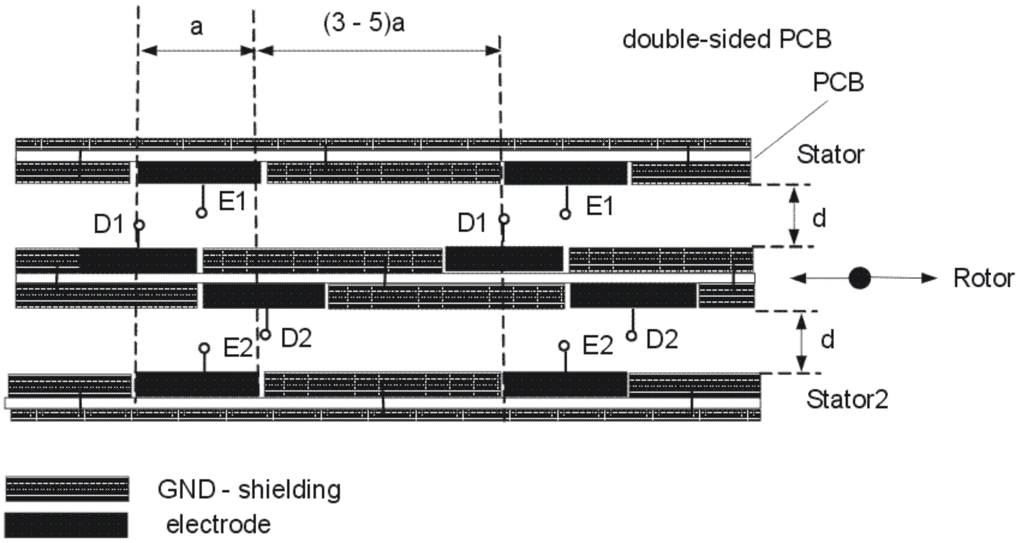

Figure 2. Side view of boards with electrodes

III. Implementation

As mentioned above this sensor is realized by the printed board circuit technology. We were handicapped in dimensions because of only a few manufacturers make boards larger than obvious ones for job-order electronics.

In expectation of future changes we had made easy adjustable scripts for program Eagle and for preparing data in Gerber format for manufacturing.

The final shape of our sensor is created as 30 degrees arc-board with external radius 500 mm and internal radius 200 mm (fig. 1). Active part is from 19 electrodes on each side (layer) of the central desk. Electrodes are realized as 5 mrad segments and are 290 mm long. Phase shift of these layers is

5 mrad. Layer diagrams are shown as zoomed detail. Active chart is surrounded by large grounded area. Central desk is moveable around centre of rotation. At distance of 1 mm from both sides will be mounted stationary boards with opposite phase-shifted shape – shift is 2.5 mrad at the initial state, zero balance (fig. 2).
There is linear relation between capacitance and deflection angle (fig. 3). In this figure you can see dependence on increasing of the coverage during a laboratory experiment. For scientific measurement we expect that the deflection of 10^{-5} rad causes change capacitance in order of 170 fF ($1.7e10^{-13}$ F).

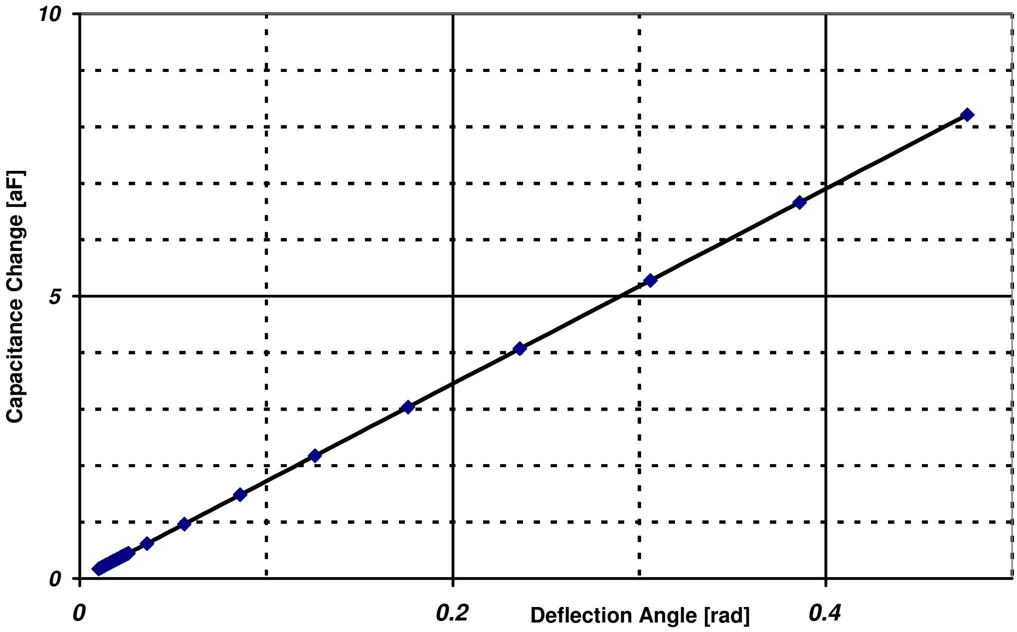

Figure 3. Linear relation of deflection and capacitance

This change is detectable by high precision balancing bridge. At fig. 4 is a principle diagram of measuring the capacitance [3]. There are used two capacitors – measuring C_m, and reference C_{ref}. Two sources of alternating currents U_m and U_{reg} with opposite phases are used. The operation amplifier serves as a current-to-voltage converter. The output signal U_{reg} regulates the amplitude of the source U_m In the equilibrium state ($I_0 = 0$) it holds the relation (3).

$$\frac{C_m}{C_{ref}} = \frac{U_m(j\varpi)}{U_{ref}(j\varpi)}\bigg|_{I_0(j\varpi)=0} \qquad (3)$$

The output is registered by a high definition, 21-bit, A/D converter Tedia into personal computer. In the future we suppose developing of a microcontroller-based device for operation in-situ.

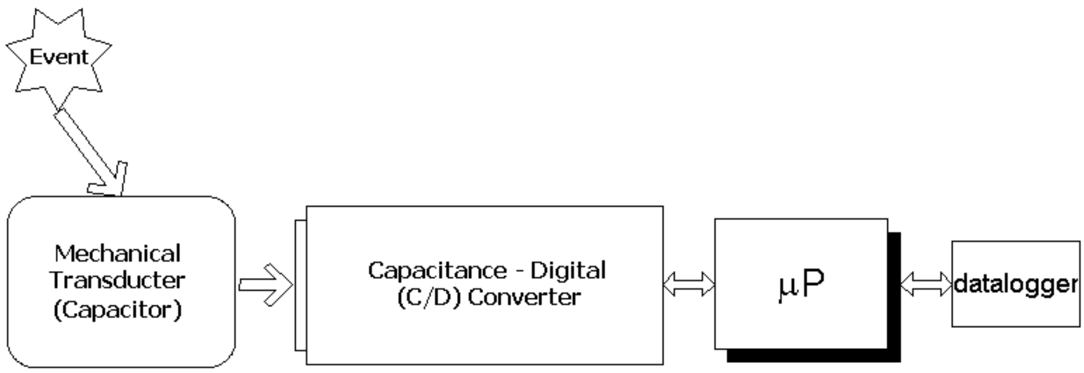

Figure 4. Block diagram of measurement

IV. Results

The first aim is reliable measuring of strong rotations induced at quarry blasts and near epicenters of earthquakes. Vibrations, exited by explosions can be used for investigation of amplitude attenuation relations of strong ground vibration. The parameters of anisotropic attenuation relations are important namely for seismic micro zoning of the storage sites of wastes. The second aim is measuring of weak long-period teleseismic waves. The first one seems to be satisfied regarding supposed amplitudes in this case in order of 10^{-3} rad. After some successful field trials we will modify sensor to reach more sensitivity. For this operation can be used one-chip microcomputer providing real-time filtering and coherent demodulation.

V. Conclusions

There are still proceeded tests of sensitivity and optimisations of construction of this kind of sensor. We are currently also applying for an international and US patent for some special solutions. At IMEKO we are going to present some interesting results of in situ test for seismology.

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