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Newly-Proposed Methods for Early Detection of Incoming Earthquakes, Tsunamis & Tidal Motion

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1. Introduction

During a last decade scientists and engineers step-by-step are developing a Single-layer Flat-Coil-Oscillator (**SFCO**)-based *new measurement technology*, and looking for its effective use in a research, and elsewhere. It was introduced in 1997 by our group in Armenia [1-2] and then improved by an integrated research group in Kyushu University, Japan, during next 4 years (1998-2002) [3-4] – allowing to reveal fine physical effects related with the basic properties of high-T_c superconductors (**HTS**) [5-8]. Starting with 2004 the method passed further development in Armenia, and was then applied for creation of a new *absolute*-position sensor of *nano*-scale resolution [9]. Advantages of the *SFCO* method-based position sensor become more evident when applied to the *quasi*-static Seismometry – to study slow movements of ground. Due to these, the *SFCO measurement technology* (in a whole [1-4]), and its first application as a novel seismic detector of slow movements (in particular [9-10]) appeared among the Top six World Security Technologies at the 2008 year's *"Global Security Challenge"* competition – details on "**GSC-2008**" forum see in: http://www.globalsecuritychallenge.com. In this Chapter, we discuss principle of operation, and test data of such a new *absolute*-position sensor, installed (for validation) in a well-known seismometer, as an additional pick-up component – showing its advantages compared to traditional technique. We discuss also wide potential of this new method, as a real-time measurement technique for early detection of incoming earthquakes, tsunamis and tidal motion. We also outline prosperous future of such a sensor.
To sense what are advantages of the flat-coil-based this unique method, let's remember: oscillators are among the most of precise measuring instruments, because the frequency is possible to measure with a very high accuracy. Among them, those at *MHz* frequencies, having volume pick-up coils (mainly, solenoid-shaped), activated by a *low*-power (*backward*) tunnel diodes (**TD**) (see [2, 11-12] and references therein), are of special interest. Replacement of such a standard coil by the unusual, single-layer flat (open-faced) one, as a detecting circuit in a stable-frequency and amplitude *TD*-oscillator, enabled to make coil's filling factor close to the maximal possible value (the *unit*) for flat objects, resulting in strong enhance-

ment of the resolution of measurements by 3–4 orders of magnitude (especially, in studies of thin, plate-like *HTS* materials [1, 3-8]). For comparison, typical values of the filling factor for solenoid coils are 10^{-4}–10^{-3} for the said samples. Advantages of the *SFCO* technique become more evident at slow movements of the objects, positioned near the coil face. Just therefore, this method has been very soon applied for the creation of a *nano*-scale *absolute*-shift position sensor, which one may successfully use in many areas: for example, for the *quasi*-static (*slow*-movement) Seismometry [9-10], in various security systems. Why this problem is so urgent? Basically, there are two types of seismic sensors, acting presently [13]: *inertial seismometers*, which measure ground motion relative to some inertial reference (*suspended inert mass*), and *strain-meters* (or *extensometers*), which detect shift between two points of the ground. Although strain-meters are conceptually simpler than inertial seismometers, their technical realization is much more difficult. Besides, as ground motion relative to the suspended inert mass is usually larger than differential motion within a test tube of reasonable dimensions, inertial seismometers usually are more sensitive to earthquakes. At low (and especially, at *super*-low) frequencies, however, it becomes hard to maintain the hanging reference fixed, and for detection of *quasi*-static deformations and *low*-order free oscillations of the earth's crust, tidal motion (*moon movement*), and for observation of mechanical vibrations of buildings, bridges, etc., the strain-meters may take noticeable lead over inertial seismometers. We describe in this Chapter how to overcome such lack of acting seismographs/accelerometers/vibrometers by the use of the recently offered by us flat-coil-based, super-broadband, nano-scale-resolution position sensor [9-10]. The more so, because further development of such a highly sensitive sensor technology may contribute also to on-time tracking (*prediction*) of potential incoming tsunamis, and monitoring of the state and zone borders as well.

2. Flat coil-based *absolute*-position sensor for *nano*-scale resolution, *super*-broadband Seismometry

And so, a new class *super*-broadband, *nano*-scale resolution position sensor is developed and tested by our group. It can be used, in particular, as an additional sensor in presently acting seismographs. It enables to extend *frequency*-band (theoretically, up to "zero"), and enhance *absolute*-resolution (*sensitivity*) of seismographs available on the market (*by at least an order of magnitude*). It allows transferring of the mechanical vibrations of constructions, buildings, bridges & ground with amplitudes over *1nm* into detectable signal in a *frequency*-range starting practically from the *quasi*-static movements ("zero"!). It is based on detection of position changes of a vibrating normal-metallic plate placed near the coil face – being used as a pick-up circuit in a stable *TD*-oscillator. Frequency of the oscillator is used as a detecting parameter, and the measuring effect is determined by a distortion of the *MHz*-range testing field configuration near the coil face by a vibrating plate, leading to magnetic inductance changes of the coil, with a resolution *1-10pH* (*depending on operation temperature of a technique*). This results in changes of test oscillator frequency. Below, we discuss work-principle, and test data of such a new position sensor, installed in a known Russian *SM-3* seismometer (for validation) as an additional pick-up element – showing its advantages compared to traditional techniques. We also discuss potentials of this novel *absolute*-position sensor, operating down to liquid–^{4}He temperatures, and in high magnetic fields – as a real-time measurement element for early detection of earthquakes, incoming tsunamis, tidal motion, and for tracking borders. We discuss also possible design of seismic detectors based on this sensor. Besides, we outline perspective future of such an unprecedented sensor – involving substitution of a normal-conducting pick-up coil by a superconductive one, and replacement of a tunnel diode by the *S/I/S hetero*-structure – as much less-powered active element in a detecting oscillator, compared to the tunnel diode. These may improve stability of oscillators, created by the use of *SFCO* method, and thus, enhance the resolution of seismic devices, and tsunami detectors as well – by at least another 2-3 orders of magnitude. Such improvements may enable to reveal and study *quasi*-static deformations and *low*-order free oscillations of earth's crust, precursor to earthquakes. It may also permit to study features of the tidal motion and tsunami waves. Such a sensor may be also used as a *position/vibration* sensing element in *micro*- and *nano*-electronics (in probe microscopy), in security systems, and in medicine as well.

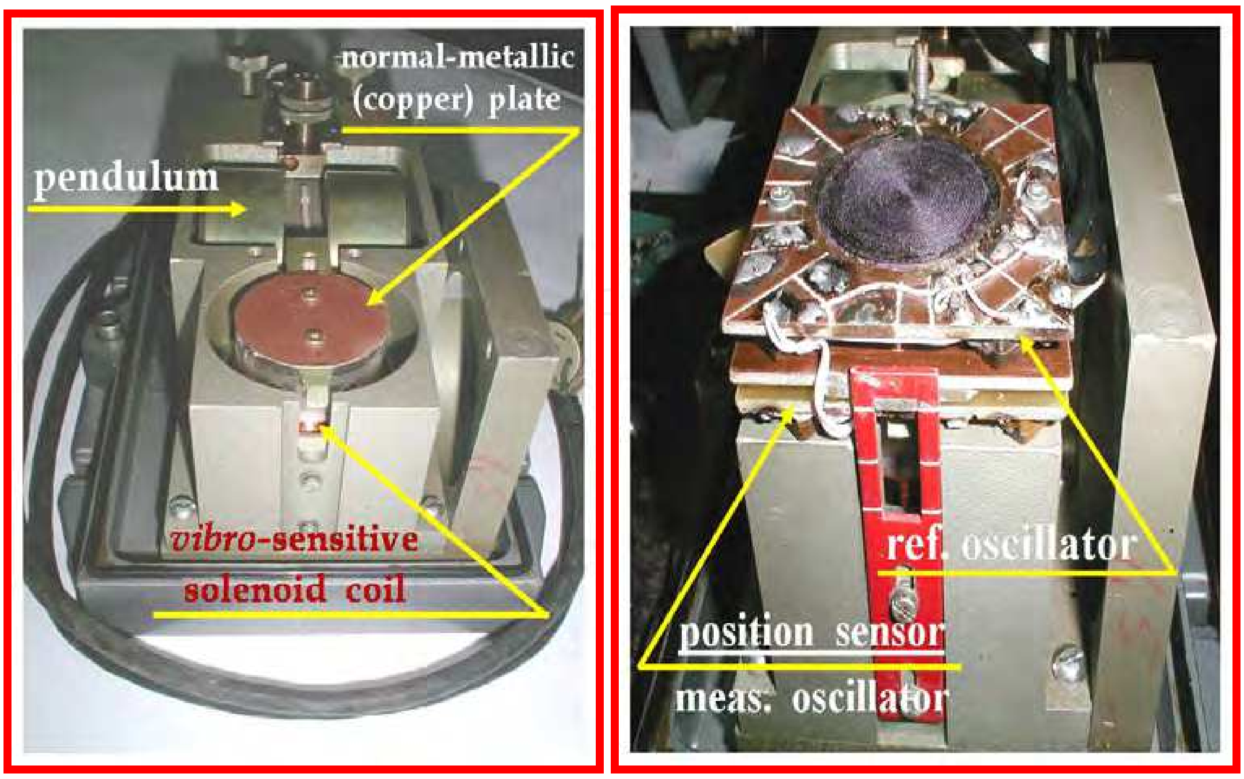
2.1 Traditional inertial seismometer

A *Traditional inertial seismometer* converts ground motion into electrical signal, but its properties cannot be described by a single-scale parameter, such as the output volts per millimetre of the ground motion [13] (*as occur in case of the absolute*-position *sensors*). Its response to ground motion depends not only on the amplitude of motion (*how large it is*) but also on its time-scale (*how fast it is*). So, the suspended (*hanging*) seismic mass has to be kept in place by certain restoring force (*electromagnetic*, *mechanical*, *else nature*). But, when ground motion is slow, the mass will move with the body of a seismometer, and the output signal even for a large motion will thus be negligibly smaller. Such a system is so a high-pass filter for ground shifts. This must be taken into account if the ground motion is reconstructed from the recorded signal. So, creation of seismic detectors, which may give large output both for fast and slow motion (*regardless of the rate of motion – as absolute-position sensors behave themselves*), still remains among the prime important problems in the Seismology (*and not only…*).

2.2 Principle of operation of new seismic detector

To this end, a prototype of the *SFCO* method-based position sensor has been created and installed by us in a setup of the Russian seismometer of *SM-3* type (Fig.1a). In such a *"hybrid SM-3"* device (Fig.1b) a flat coil serves as a pick-up in a stable *16MHz*–oscillator, driven by a *low*-power Russian tunnel diode of the *AI-402B* model. Actually, 2 similar flat-coil oscillators are mounted in *SM-3*. One is used as a position detector, the other – to detect background at all times (*bottom* and *top* oscillators in Fig.1b respectively). Let-in *SM-3* position sensor is extra to its own *vibro*-sensor one, based on excitation of the electromotive force (**EMF**) in a solenoid coil (Figs. 1a and 1c). In case of the *SFCO*-based sensor, measuring effect is proportional to changes of mutual distance between the coil and metallic plate vibrating parallel to the coil face (*d* in Fig.1c). This results in the changes of the *test*-oscillator frequency.

So, new seismic detector converts ground motion into shift of a flat-coil-oscillator frequency – *due to ground shaking*. The measuring signal appears as a result of the coil motion (fixed on seismograph's body – Figs. 1b-1c and 2) relative to metallic plate (fixed on hanging pendulum (Fig.1c), or membrane (Fig.2)), positioned near the coil. Figures. 1c and 2 schematically illustrate *SFCO* sensor-based novel seismic detectors' possible designs: F_S is the shock force, and *d* – amplitude of vibration of a pendulum (see Fig.1c) or membrane (Fig.2), caused by it.



a) b)

Fig. 1. a) Top view of the *original Russian SM-3 seismograph*, with the light metallic (*copper*) plate additionally screwed on its vibrating pendulum (*schematics see in* Fig.1c). Initially, the *SM-3* device is designed to detect vibrations in a frequency range from *0.5Hz*, and up to *50Hz*.
b) Front-view of the *original Russian SM-3 seismograph*, with additionally installed package with 2 flat-coil-based oscillators – named as the *"hybrid SM-3"* seismograph.

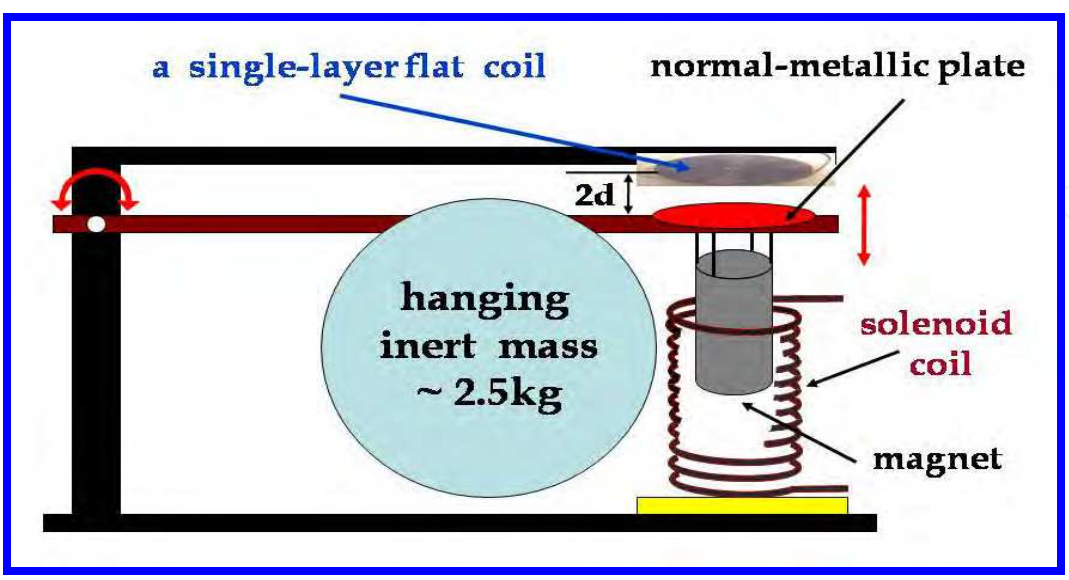


Fig. 1. c) Mechanical schematics of the *"hybrid SM-3"* seismograph – advanced by the use of *SFCO* method-based highly sensitive, *super*-broadband position sensor: *d* is the amplitude of vibration of a pendulum, caused by the ground shaking.

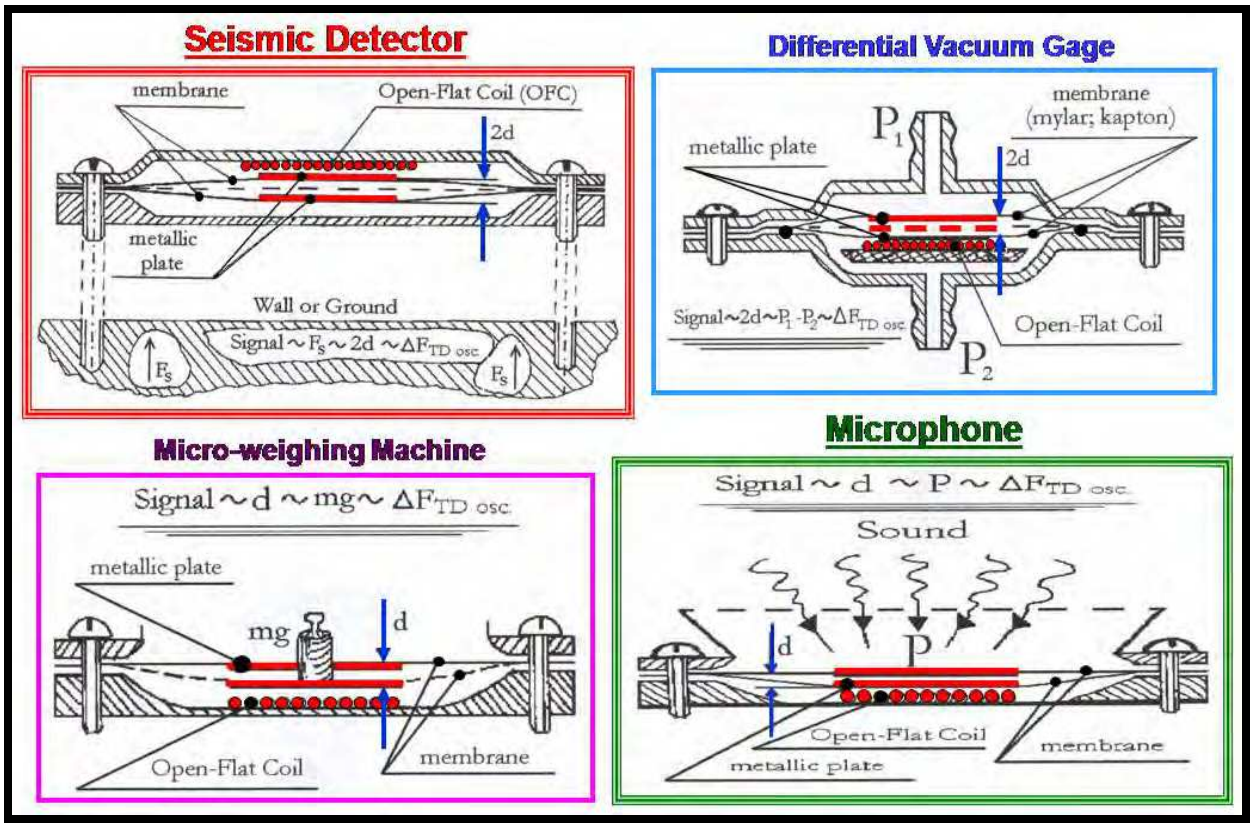


Fig. 2. Mechanical schematics of the *SFCO* sensor-based fully novel 4 techniques: seismic detector, differential vacuum gage, microphone, as well as micro-weighing machine: F_S is the shock force, d – the amplitude of flapping of a membrane, caused by the ground shaking.

2.3 Flat-coil based measurement technology: Its advantages

A single-layer flat-coil-oscillator test method (the **SFCO** technique [1-2] – it is introduced by our group in 1997, its electrical scheme is shown in Fig.3) is a fine research instrument for doing *MHz*-range, sensitive measurements. It can be used for determination of too much little changes of distances with $\Delta d \sim 1\text{-}10\text{Å}$ absolute and $\Delta d/d \sim 10^{-5}\text{-}10^{-6}$ relative resolution (depending on a model and working temperature of the *TD*-oscillator [3-4]. It is also a sensitive radio-frequency (**RF**) *Q*-meter – to study absorption as small as $10^{-9}W$ in thin flat materials (for example, in plate-like high-T_c superconductors [5-7]). The *SFCO* method can operate down to the liquid–^{4}He temperatures. Presently, it is tested by us up to *12T* magnetic fields [7]. The method differs from the known "*LC*-resonator" technique (see, for example, [14]) by replacement of the volume-shaped testing coil by the unusual single-layer flat (open-faced) one. Additionally, it is driven by the *stable*-frequency, *low*-power tunnel diode.

Advantages of the *SFCO* method-based sensor become more evident when applied to *quasi*-static Seismometry – to study slow movements of ground. In this regards, Fig.4 compares responses of the *SFCO* position sensor and the *EMF*-based *world*-best *SM-24 ST vibro*-sensor (geophone.com) – against the same vibrations. The vertical size of the blacked-out region in this Figure shows advantages of our novel *SFCO*-sensor for different values of vibration frequencies. One may conclude from the Fig.4, that advantages of the *SFCO* method-based new sensor become much more evident at *super*-slow vibrations (*movements*), with F< *10Hz*.

Both the frequency and amplitude of the oscillator are used as testing parameters in a *SFCO* technique. The measuring effects are determined by a distortion of the coil testing field

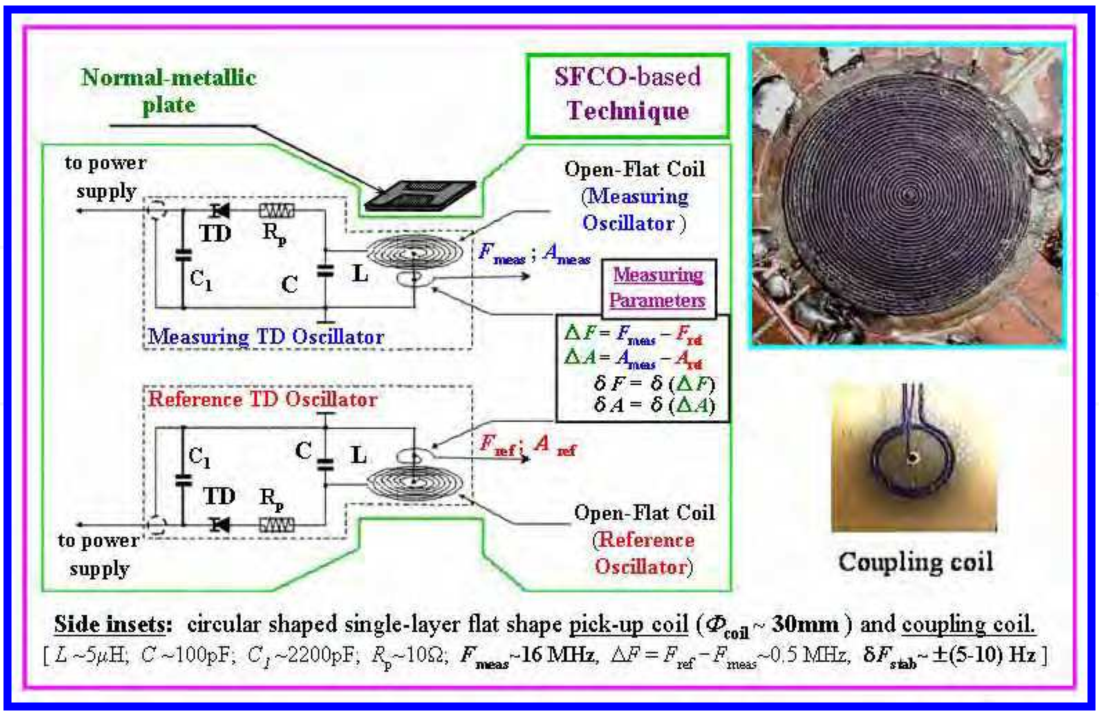


Fig. 3. Electrical schematics of the new seismic detector, based on *SFCO* technique (single-layer flat-coil-oscillator, driven by the *stable*-frequency, *low*-power tunnel diode (**TD**).

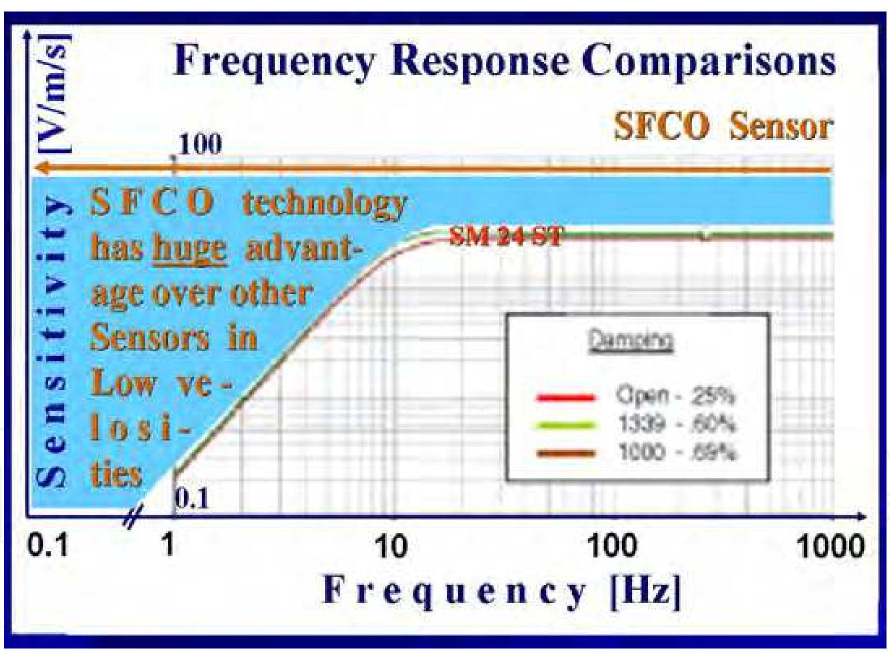


Fig. 4. Comparision of the *SFCO*-based *absolute*-position sensor with an electro-motive-force (**EMF**)-based *world*-best *SM-24 ST vibro*-sensor (geophone, see: www.geophone.com).

configuration near its flat face, and by the absorption of the same field's power by an object under test (*due to external influences*). These finally result in the changes of test oscillator frequency and/or amplitude, respectively. Compared with the traditional (*volume*-coil) method, in a flat-coil technique testing *RF*-field is densely distributed near the coil face. Besides, due to flat shape, even a little shift of the position of a *normal*-conducting plate, placed near the coil, may lead to strong distortion of the field distribution around the coil. These features, and the stability of *TD*-oscillators ($\Delta F_{stability}$~*1–10Hz*, $\Delta F/F$~10^{-7}–10^{-6} – depending on the model & temperature – see [2, 11-12]) enabled us to reach 6 orders relative resolution in *SFCO* technique [3-4], permitting to effectively use it in a basic research [5-8], as well as in some modern technical applications [9-10]. In the last case, frequency of the oscillator is mainly used as a testing parameter, and the measuring effect is determined by a distortion of the *MHz*-range testing field configuration near the coil face by the vibrating copper plate, leading to the magnetic inductance changes of the coil, with a resolution ~ *1-10pH* (*depending on operation temperature of a technique*), resulting in the changes of test oscillator frequency.

2.4 Reconstruction of ground motion from recorded frequency-shift of *TD*-oscillator

Since electro-motive force based traditional *vibro*-sensors (included, the own sensor of *SM-3*) and suggested by us position sensors are various nature devices, with different outputs (*EMF*-based sensor converts ground motion into output volts, while flat-coil-based novel sensor converts the same motion into the shift of test-oscillator frequency), there are no direct ways to compare them properly, except that one may compare their responses over the respective noises during the same shaking. And so, we tried to detect and compare signal-to-noise (**S/N**) ratios for these two (*different principle of operation*) sensors, during the same experiment – against the same *1-2Hz* time-scale weak vibration.

In this regard, note that for correct reconstruction of the ground motion from the recorded frequency shift there is need to properly calibrate the *SFCO* method-based this non-traditional technique. The problem here is much complicated compared with the cylindrical (*solenoid*)-coil based technique, since even for the simplest case of a weakly vibrating thin conducting plate near the flat coil the calibration data are dependent on the used plate's diameter. For comparison, in case of cylindrical (*solenoid*) coil-based similar technique one needs calibration for only one (*given volume*) cylindrical sample, placed in the homogeneous testing field area inside the coil. Then, the obtained *calibration*-data can be expanded and used for any other shape and volume samples, provided that they are positioned anywhere inside the almost homogeneous-field area, near the cylindrical coil center [14].

So, below we discuss briefly the method, and results of calibration of the tested flat coil's *RF*-field configuration, by the use of a normal-conducting (*copper*) plate enabling correct transfer of the measured shifts of frequency δF, to the changes of distance δd, from the coil face d. One of possible ways to do that seems the calibration by moving the *given*-size *disk*-shaped copper plate towards the coil's face, up to the given distance, d, and back. This strongly changes the coil's testing field configuration (*and thereby, oscillator frequency*), and enables the empirical estimation of the so-called *G*-factor – as the coefficient for the coil's inductance (*resonant frequency*) modulation. Changing the position of the metallic object, we could experimentally determine the value of the *G*-factor as the relation between the resonant frequency modulation δF and the change in position δd. Figure 5 presents and illustrates the results of such calibration of the created position sensor (*let-in the SM-3 seismic device*) – which we realized. As is seen, the empirically determined $G(d)$-factor (*which actually is the absolute resolution of the technique*) for the given area metallic plate depends on the position d, near the flat coil. *G*-factor enables correct transferring of the measured shifts in frequency to the linear changes in distance by the formula: $\delta d \equiv -G(d) \times \delta F$, important for the proper reconstruction of the ground motion from the recorded *frequency*-shifts. Figure 5 shows that *G*-factor depends strongly on distance from the coil face. Namely, sensitivity (*absolute* *resolution*) drops exponentially with an increasing distance – due to sharp drop of a testing field density. G_w ~ *1Å/Hz* in Fig.5 is a typical value of a geometric factor achieved for the F_{meas} *~16MHz* operating frequency and Φ_{coil} *~30mm* coil oscillator on *d~1.1mm* distance from the coil face, at liquid–^{4}He temperatures (*typical stabilities reached for TD-oscillators at low temperatures are* $\delta F_{stability}$ ~ ± (**1-2**) *Hz* – see Fig.6b) [3-4, 15]. At the room temperatures, the noise level of the tested flat-coil sensor (*let-in the SM-3 seismic device*) is a little bit worse – close to ± (**5-10**) *Hz*.

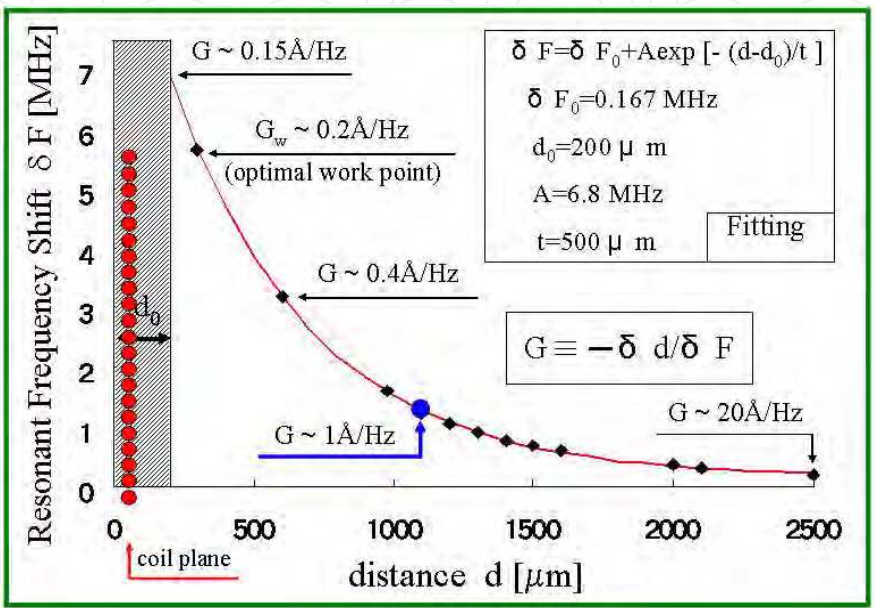


Fig. 5. *SFCO* technology-based position sensor sensitivity vs. the distance from the coil flat face: testing *RF*-field's density vs. the distance from the open-flat coil's face in a *SFCO* position sensor.

Note that such a low noise level of the tested sensing system is due to changes in inductance caused by all internal factors in the system's electronics, and mechanics. To be sure in this matter fully, we fixed mechanically (*for a long time*) the pendulum of the *"hybrid SM-3"* (see Figs. 1a - 1c), and tried to detect noise level of the measuring oscillator. Its stability was close to ± (**5-10**) *Hz* at room temperatures, during an hour. And so, distance *d* can be taken as a unique factor to determine inductance changes in measurements (*due to vibration of a copper plate near the coil face*) in the range of resolution corresponding to the frequency shift of about ± (**5-10**) *Hz*, at room temperatures. Hence, for the Φ_{coil} *~30mm* coil sensor, installed in *"hybrid SM-3"* (*with the copper plate, vibrating near the coil face, at a distance d~1.1mm*), we reached a resolution $\delta d = G \times \delta F_{stab} \sim 1 Å/Hz \times \pm$ (**5-10**) $Hz \sim \pm 1nm$ at the room temperatures (see Fig.5).

2.5 Novel seismic detector based on SFCO measurement technology (test-results, discussion, future perspectives)

2.5.1 Test-results

Thus, because there is no other reasonable ways for direct comparison of the said 2 different nature (*principle of work*) sensors we tried to compare their responses over respective noises, during the same shaking. So, we detected, and below compare, the signal-to-noise ratios for above sensors – during the same experiment, against the same *1-2Hz* time-scale weak vibration. Comparative-test data of such an experiment are shown in Fig.6. In our tests, the *"hybrid SM-3"* was fixed to the glazed-tile floor of a laboratory room, situated on the 2-nd floor.

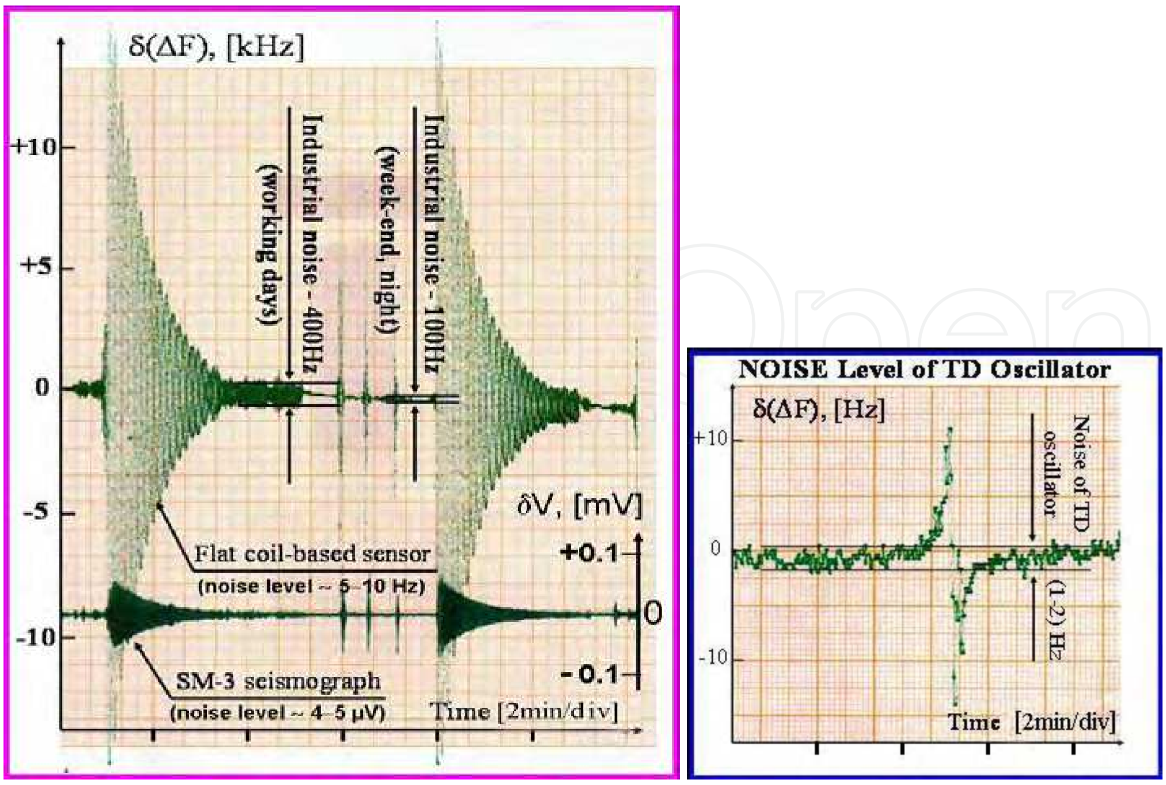


Fig. 6. a) Comparative-test data of the flat-coil-oscillator based *absolute*-position sensor (left vertical scale – δ(Δ*F*), [kHz]) and *EMF*-based *vibro*-sensor (right vertical scale – δ*V*, [mV]) – both installed in the same *"hybrid SM-3"* seismic device. Room-temperature noise levels of both sensors are also pointed out in the figure (~ *5-10Hz* and ~ *4-5μV*, respectively).
b) Noise level (*stability*) of a tested *TD*-oscillator at liquid–^{4}He temperatures, permitting to estimate an extreme resolution one may reach in *"hybrid SM-3"* seismic device, supposing that its *SFCO* novel position sensor is cooled down to 4K. Note, that the room-temperature noise level of the tested *SFCO* sensor is a little larger – close to ±(*5-10*)*Hz*. The room-temperature noise of the *SM-3*'s *EMF*-based own *vibro*-sensor is about ~ *4-5μV* – see Fig.6a.

First, from data shown in Fig.6a one may conclude that, as detected by a *SFCO* position sensor, the level of background vibrations of a laboratory floor is near ±*400Hz* – during workdays. Taking into account the above said value of about *1Å/Hz* for the *G*-factor at *d~1.1mm work*-distance from the coil (see Fig.5) such level of background vibrations corresponds to the amplitude of vibration of the laboratory floor of about ±*40nm*. Besides, Fig.6a indicates that background vibrations of our laboratory building were almost 4 times stronger at workdays, compared to weekends and nights. Even such shakings at nights, however, almost *50* times exceeds the measured noise level (of about ±*1-2Hz* – Fig.6b) one may get in created *"hybrid SM-3"* seismic device – provided that its *SFCO* position sensor is cooled down to 4K. Background shakings of the laboratory room might be caused by the industrial pumping of an environment, and besides, by the vibration of earth's crust. Background shakings might be caused also by rocking during the tests of a technical nature. In this regard, note that a fine signal, seen in Fig.6b, detected by our *SFCO* method-based new sensor, is an evidence of its high abilities. The signal is result of beating of the measuring *TD*-oscillator with a little signal "coming" from the close-located broadcasting station. An acting seismic station is under creation in Yerevan State University, based on created *"hybrid SM-3"* new seismographs, capable of providing LabVIEW environment-based data acquisition and processing (Fig.7).

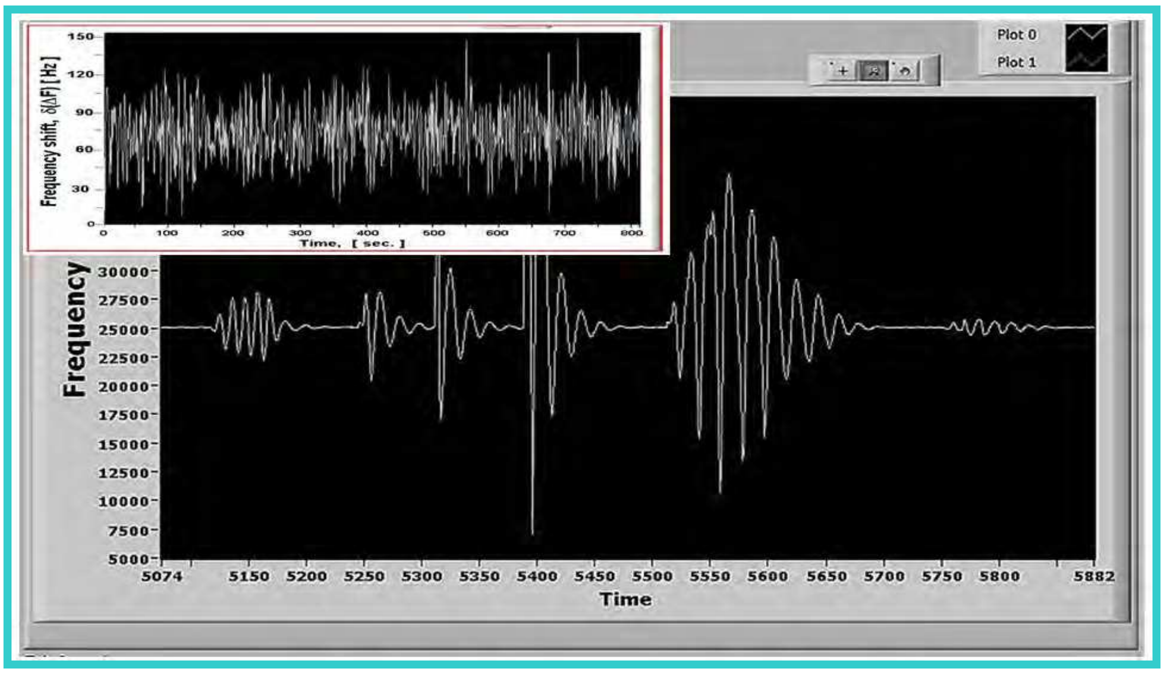


Fig. 7. LabVIEW signals of our new *SFCO absolute*-position sensor-based inertial seismic detector (the *"hybrid SM-3"* seismograph) for different amplitude shakings, ranging from ±25 to ±250nm, at the background vibration of about ±5nm (see inset on *top left*). Background-vibration LabVIEW signals of the *SFCO*- sensor based new inertial seismic detector. Experiments were conducted at the night time-period, to achieve as low as possible noise level at room temperature in a technique caused by the industrial rocking of an environment and vibration of the earth's crust.

2.5.2 Discussion

Comparison of signal-to-noise ratios (at F~1Hz), for new sensor (*flat-coil based SFCO sensor* – $(s/n)_{flat\text{-}coil}$ is about 16kHz/(5-10Hz) ≅ 1600-3200) and for *SM-3* sensor ($(s/n)_{EMF\text{-}sensor}$~150μV /(4-5μV) ≅ 30-35) – both operating in the same *"hybrid SM-3"* seismograph – permits to conclude that the *SFCO* sensor is more sensitive by about 50-100 times (see Figs. 6a and 8). Besides, since the *SFCO* sensor allows detecting of *absolute*-position shifts (see Fig.4, low frequencies), it may enable to detect very beginnings of *quasi*-static deformations and oscillating processes in earth crust – at very low frequencies – in contrast to the traditional *EMF*-based sensors, being used practically in all acting inertial seismometers of a different design. This is the case since *EMF*-sensor may not detect slowly passing processes – due to minor voltage arising in solenoid pick-up coils during the slow movements of a pendulum (Fig.1c). So, in order to effectively detect *quasi*-static deformations by the *SFCO* technology-based *absolute*-position sensor, one should build and use a properly vibrating mechanical pendulum (*with a mass as heavy as possible*, and *with as weak as possible restoring force of the mechanical part of pendulum*) – something like to what is the case in Russian *SM-3* detector, but with less friction against the motion of a freely hanging pendulum. *EMF*-based sensor may not detect slow processes, at any case, since it is a velocity sensor. This all may become crucial for detection of low-order free oscillations of the earth crust, and for observation of the peculiarities of a few-hour duration tidal motion & tsunami shaping. That is why one should use the *SFCO absolute*-position sensing technology (in this, or another modification of a sensor – *see schematics of different sensors in Fig.2, to be used depending on the application*) to reveal in advance, and study origins of formation of earthquakes, tsunami waves, and tidal motion – *impossible, in principle, for other methods*. We believe this offer holds considerable potential for meeting advanced technical needs of the seismic & tsunami services supported by governments of practically all countries positioned in the seismically active regions of the world.

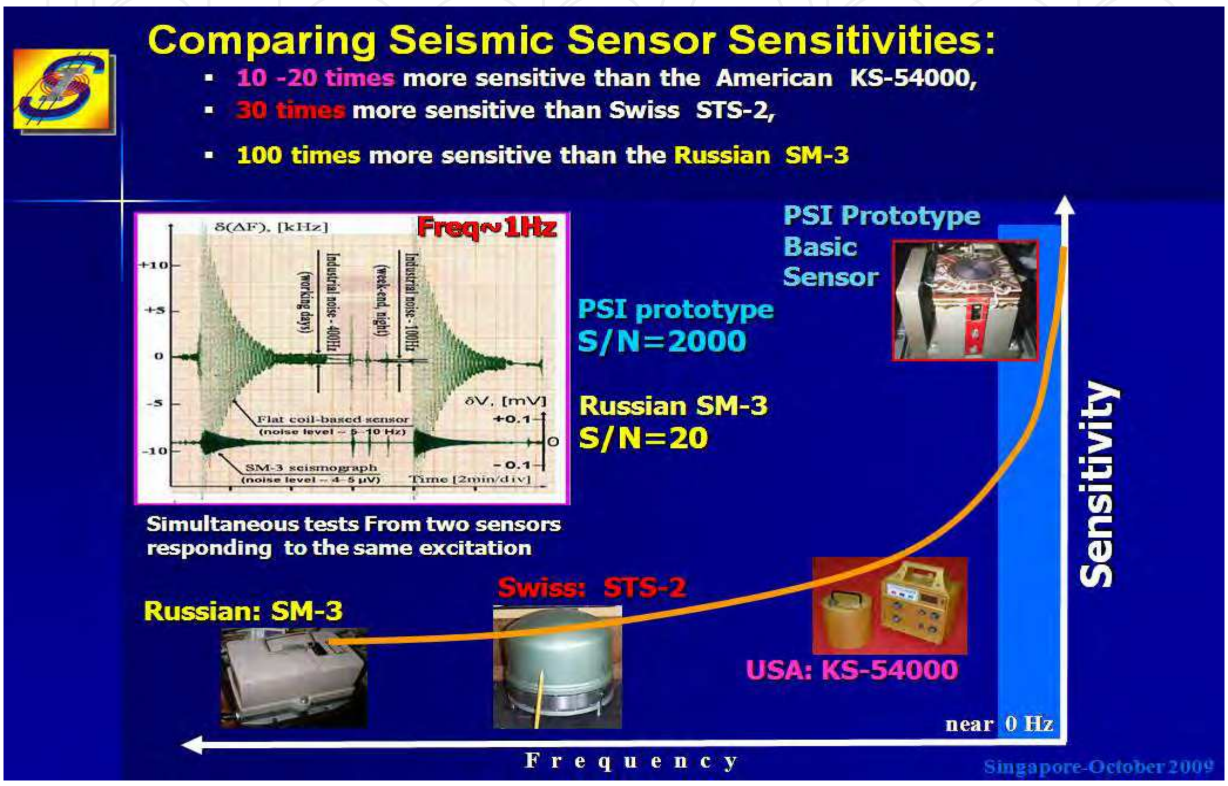


Fig. 8. Comparision of *"hybrid SM-3"* seismic detector (based on a *SFCO* technology *absolute*-position sensor), with the *EMF* principle of operation based other word-wide detectors.

In this connection, we bring in a next Fig.8 comparative data, related with the *SFCO absolute*-position sensor technology-based *"hybrid SM-3"* and the *EMF*-based word-wide seismic detectors. Comparison is again made at vibration with F~1Hz. Taking into account huge advantages of the *SFCO* position sensor technology over the other sensor technologies (especially, at vibrations with F < *10Hz* – see Fig.4) much higher sensitivity of the said *"hybrid SM-3"* detector (having inside integrated *SFCO* sensor, as the additional sensing element) becomes evident. As to the vibration frequencies below the 1Hz, the *EMF*-based all seismic sensors loss their row sensitivity at al (sensitivity, without long-time and expensive integrating electronics) – see Fig8 and Fig.4.

2.5.3 Future perspectives

There are many ways how to even more enhance the resolution of such new *absolute*-position sensors, and, as a result, capabilities of the presently acting *inertial seismometers* – even by the several orders of magnitude. For that purpose, the pick-up flat coil, and/or the active element of the measuring oscillator should be made of superconductive material (high-T_c or low-T_c – for better stability). In other words, one of the relatively easier ways relates with the replacement of the normal-metallic coil by the superconductive one. This may improve the tunnel diode oscillator stability by at least 1-2 orders of magnitude [2]. The next improvement relates with the substitution of the tunnel diode by the superconductive *S/I/S* hetero-structure – as much more less-powered active element (*compared to tunnel diodes*) for the measuring oscillator of the *SFCO absolute*-position sensor, with a few orders of magnitude less steep of its *I-V* curve's negative differential resistance [16]. This may raise the oscillator stability by another 2-3 orders of a value [2]. Even these two modernizations are enough in order to enhance the stability of the measuring and reference oscillators of such a technique (Fig.3) and hence, to increase the signal-to-noise ratio (*sensitivity*) of the *SFCO* technology-based seismic detectors – by at least 3-4 orders of a value. As follows from the Fig.5, the *absolute*-resolution of such a new sensor drops exponentially when a normal-conducting plate moves away from the coil face. This property of *SFCO* sensors makes easy adjustment of the sensitivity (*resolution*) of such a new position sensor, for various practical usages in future.

3. Areas for specific application of SFCO *absolute*-position sensors

Besides the usage of the SFCO technology - based *absolute*-position sensors in seismic predicttion & protection, they might be also effectively applied in: *security systems*; *geophysics & town-planning; micro- & nano-electronics; military science*, *engineering & intelligence;* etc.:

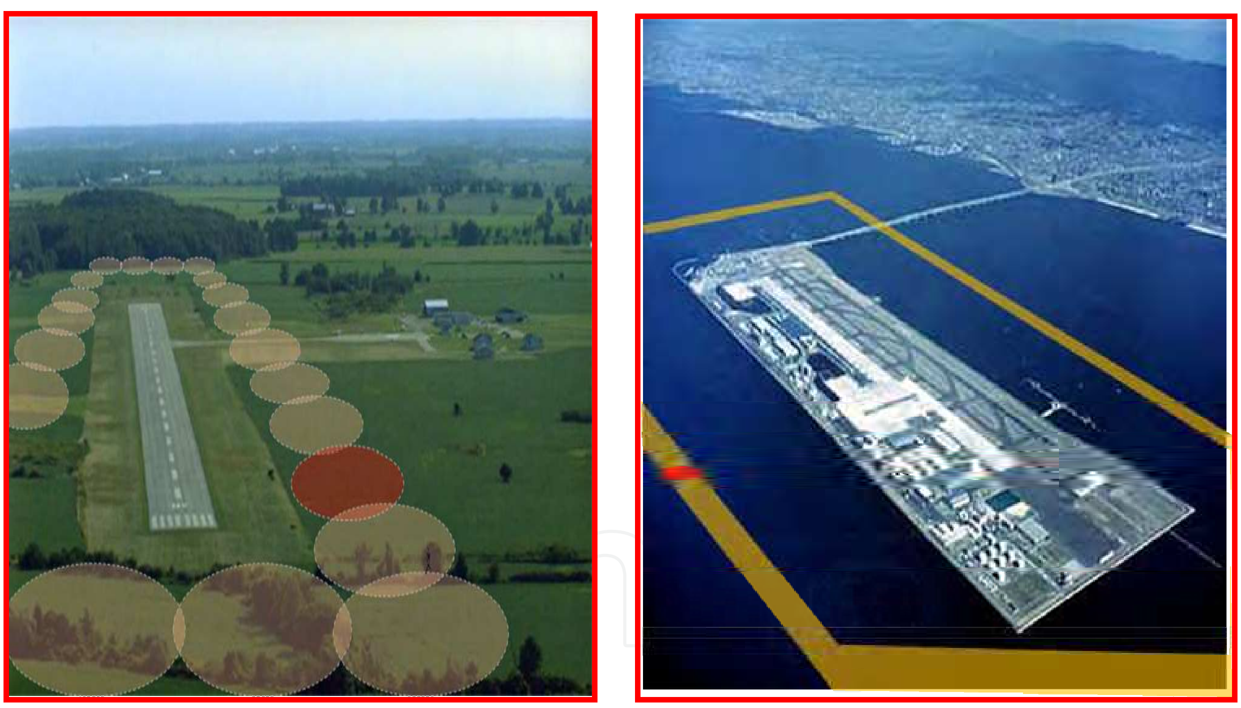


Fig. 9-10. The *SFCO*-sensor based *Early Warning Security System* can secure the runway and specific underwater perimeter with the invisible and totally passive security net, and can detect over the ground and underground, as well as underwater moving intruders.

in security systems: The new (**SFCO**) technology *absolute*-position sensor-based ultra-sensitive seismic detectors and vacuum gages may give rise to many markets & applications, and bring to products that can serve both military & civilian applications. Early warning security systems (**EWSS**) are natural applications that can serve to protect State & Federal borders, provide Ports security & control, as well as Civilian applications of perimeter security

Fig. 11. The *SFCO*-sensor based *Early Warning Security System* can secure the ground and underground, as well as specific underwater perimeter with the invisible and totally passive security net, and identify the location of underwater moving intruders.

controls such as security of oil pipelines, airports, and private properties. The new technology sensors may also enable detection and recognition of various mobile targets (*walking or crawling man*, *vehicles*, *tanks*, *or other human activities*) approaching any zone (*military camps, state properties, banks, or other critical high priority infrastructures*) or borders without the need of physical line of sight.

Figures 9 through 11 are pictorial depictions of systemic applications to real world security scenarios, showing the flexibility and versatility of this new technology rendering one of the highest quality EWSS for military or civilian applications, covering detection for underground movements, over the ground movements, and underwater movement.

in geophysics and town-planning: for gas and oil prospecting, and also to reveal too much weak vibrations and slow bending (*twist*) of the buildings, constructions and bridges, as well as for permanent monitoring of old bridges aging;

in micro- and nano-electronics: for creation of *New Generation* microscopes with long-range action "*magnetic-field*" probes.

Our recent research shows [17-18], that flat coil based *TD*-oscillators can be activated also with their internal capacitances (*without an external capacitance C in their resonant circuits* – see **Fig.3**). That is the result of relatively high value of internal capacitances of single-layer flat coils compared to their parasitic capacitances with respect to the surrounding radiotechnical environment. This opens one more exotic area for flat-coil oscillator application. Namely, a "*needle-like*" testing magnetic field of such a flat coil (see **Fig.12a**), used as a pick-up in such a stable *TD*-oscillator, enables a novel method (*new approach*) for surface probing, based on replacement of short-range, solid-state probes of acting microscopes (*such as needles or cantilevers of tunneling* [19-20] *and atomic-force* [21] *microscopes*, *probes of the near-field microscopes*, etc.) by the long-range action non-solid-state ones. Such an unusual probe shows strong dependence of a detected signal on the size of the spatial-gap between the probe and the surface of the object – crucial for the probe microscopy (**PM**) [22]. This opens an opportunity for creating of the "*magnetic-field*" probes with a *RF* power applied to the sample lying in the range of 1nW to 5μW. The gap between such a "*probe-formative*" flat coil and the object can be larger than 100μm [18], compared with the 1nm gap of the acting probe microscopes [22]. In our tests we reached a lateral resolution ~ 1μm even for the relatively large diameter ($2R_{coil}$ ~ 14mm) flat-coil technique [18].

Such a *SFCO*-probe may also "*notice*" and distinguish details of the relief of the normal-metallic object – with about 10μm spatial-resolution, presently (**Fig.12**). In order to demonstrate that, we performed an experiment with one-dimensional (**1D**) metallic grid made of 6 copper wires (see **Fig.12a**): each wire was ~20-30μm in dia. and was positioned with an average interval of about 200μm between the wires. Copper wires distort the coil *RF*-field configuration when they move (*or*, *when the coil moves relative to the grid*), leading to changes of the oscillator frequency or/and amplitude. The effect is maximum when each wire reaches to the coil center. **Fig.12b** illustrates detected dependence of the oscillator frequency shift, $\delta(\Delta F)$, vs. the lateral position of the metallic-comb relative to the flat-coil face (*relative to "magnetic-field" probe*). Average distance between the detected 6 vertical neighboring peaks on the curve in **Fig.12b** is ~200μm – just in agreement with the experimental setup in **Fig.12a**. That is why, we believe, that *SFCO*-probe may also in future distinguish (*both by amplitude and frequency of the TD-oscillator*) details of the relief of the magnetic or metallic 2D grids, in *sub*-micrometer scales. For such high lateral resolution, there is need to work out and create the *SFCO* method-based advanced "*magnetic-field*" probe, with a lithographically made single-layer flat coil of about 1mm in diameter [23] – *as an effective needle-type probing instrument with better than* 100nm *predicted lateral resolution*. Such a radically new probe will have considerably *large work-distances* (more than 100μm) *between the probe and surface of the object*, which enables a "visual" control of the local area of probing of the object, and, if needed, application of test perturbations (for example, exposition to laser radiation).

in military science, engineering and Intelligence: to detect onset and amount of attacking soldiery of enemy arm-forces in the absence of direct visibility, and to reveal and detect low-powered nuclear weapon tests. Besides, to solve the perimeter or/and zone-security problems for the intelligence group(s), as well as for the special mission unit(s).

In a precision sensor industry: for creation of non-contact acceleration sensors (*the pickups*) of *super*-high resolution.

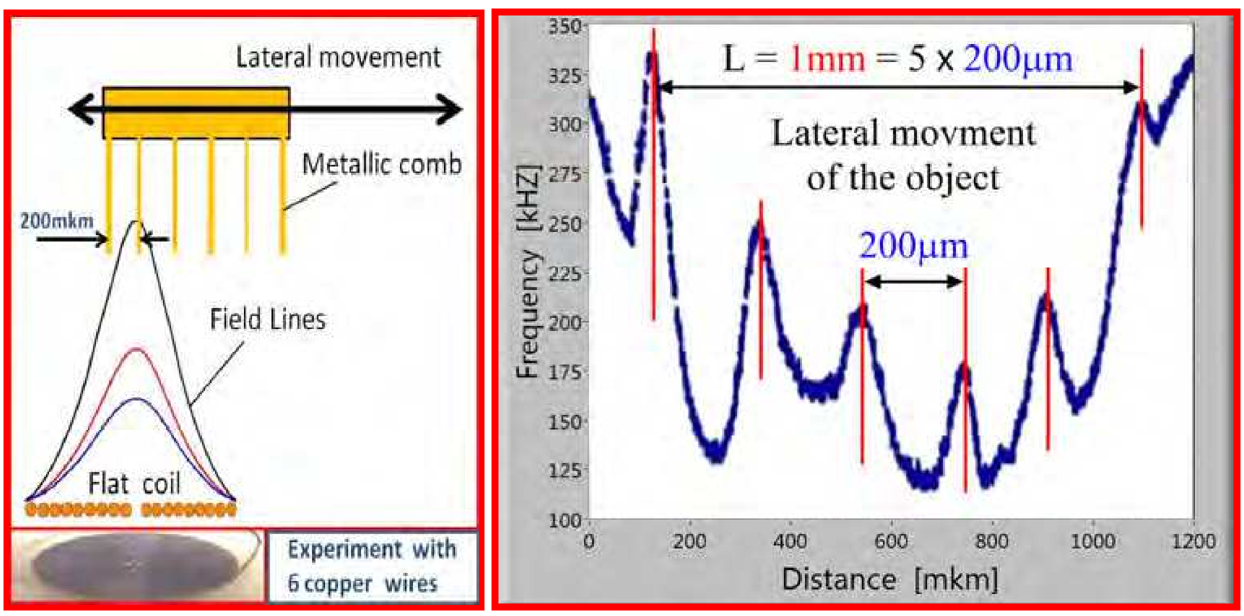


Fig. 12. Dependence of the *SFCO* technique's *TD* oscillator frequency shift *δ(ΔF)[kHz]* (**b**) on the lateral position of the *1D* grid-shaped metallic object (**a**) relative to the "*probe-formative*" flat coil face.

in a basic research: for high-precision measurements of the Casimir Force and very little friction related with it. Besides, high- and/or low-T_c superconductive coil-based 3D analogue of such a new, ultra-sensitive *SFCO*-position sensor seems to be very useful also for the *sub*-Angstrom *spatial*-resolution gravity-wave detection.

4. Conclusion

A new class super-broadband nano-scale-resolution position sensor appeared quite recently. It can be used, in particular, as an additional sensor in seismographs. It enables to extend the frequency-band (up to "zero"), and enhance the absolute-resolution (*sensitivity*) of the vibrometers and seismographs, available on the market, by 10-100 times, depending on the model of the base product (such as the American KS-1/KS-54000 and FBA-23, the European GS-13 and STS-1/STS-2, and the Russian SM-3 – presented and discussed above *SFCO*-sensor was installed just inside the SM-3 seismometer, and compared with its own sensor).

The new position sensor allows transferring of mechanical vibrations of the constructions, buildings & the ground (earth crust) with amplitudes over 1nm, into detectable signal in a frequency range starting practically from quasi-static movements ("zero"!). Such high is the achieved resolution, because due to much higher precision one may measure the frequency of oscillator, compared with the inductance or capacitance of its resonant circuit (even, if use more sensitive AC-bridge technique), oscillators are most suitable sensors for high-precision detection. This is why a very similar position sensor, based on the inductance-change detection of a lithographically made single-layer flat geometry coil, enables three orders less resolution in absolute position sensing [24]. Operation of the new sensor is based on detection of the position changes of a vibrating normal-metallic plate placed near the single-layer flat geometry coil – being used as a pick-up in a stable tunnel diode oscillator. The frequency of the oscillator is used as a detecting parameter in such a sensor, and the measuring effect is determined by a distortion of the *MHz*-range testing field configuration near the flat coil face by a vibrating plate, leading to the magnetic inductance changes of the coil, with a resolution ~10 pH. This results in changes of measuring oscillator frequency.

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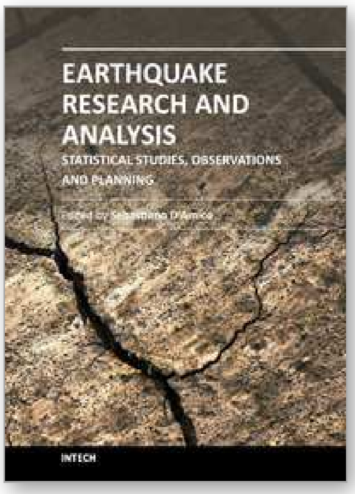

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The study of earthquakes plays a key role in order to minimize human and material losses when they inevitably occur. Chapters in this book will be devoted to various aspects of earthquake research and analysis. The different sections present in the book span from statistical seismology studies, the latest techniques and advances on earthquake precursors and forecasting, as well as, new methods for early detection, data acquisition and interpretation. The topics are tackled from theoretical advances to practical applications.