Proceedings of the 2003 IEEE International Frequency Control Symposium and PDA Exhibition Jointly with the 17th European Frequency and Time Forum

Poster session
Group 1.B

FORTY-YEARS HISTORY OF DEVELOPMENT AND UP-TO-DATE STATUS OF INDUSTRIAL TYPES OF INTERNALLY HEATED QUARTZ RESONATORS (IHQRs) AND OSCILLATORS ON THEIR BASIS

YAKOV L. VOROKHOVSKY, INNA G. PETROSYAN, ALEXANDER A. VOLKOV

Morion, Inc.: 13a KIMa Avenue, St. Petersburg, 199155, Russia

Creation of Internally Heated Quartz Resonators (IHQRs) as a special type of devices combining functionally and technologically a quartz resonator proper and an oven was caused by an aspiration to overcome the shortcomings of quartz resonator traditional ovenizing, i.e. large power consumption, overall dimensions and warm-up time, low resistance against severe environmental conditions.

Many stages of the industrial IHQRs' development are connected with St. Petersburg Company Morion, Inc., where work on IHQRs was started in the middle of the sixties of the 20^{th} century by the team of P.S.Kukanov-Artemov, V.A.Romanov, N.I.Sizov, etc. The first industrial type of IHQRs was one with bimetallic oven's switch combined with quartz blank's holder, developed in 1965-66 based on the inventions by B.G.Preobrazhensky [1,2], who was an employee of the Institute of Communications of the Defense Ministry. This type of IHQR shown in Fig. 1 was put in serial production and was used in the military mobile and portable radio stations since 1967 till 1980. For that time those IHQRs with frequency of 2.0 MHz were highly efficient, having the frequency stability $\pm(1.5\ldots2)\cdot10^{-6}$ vs. temperature change from –50 up to 70°C, power consumption of 1.0W, warm-up time of 15 min. and volume of 50 cub.cm.

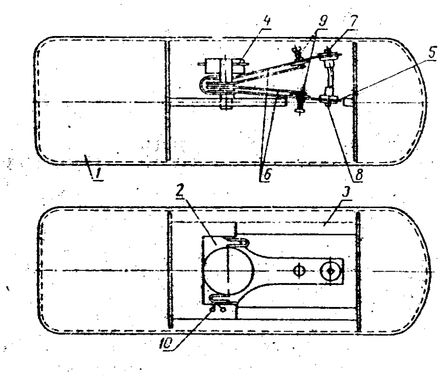

Fig.1 IHQR with a bimetallic switch:
1 - vacuum glass bulb
2,3 - holder's parts
4 - quartz blank
5 - steel plates of the switch
6 - bimetallic plates
7,8 - contacts
9 - adjusting screws
10 - heater

Within the time period of 1967-74 the group of P.S.Kuckanov took strong efforts to improve the mentioned parameters and resistance against shocks and vibration that was a weak point of this type of IHQRs. Two new models of IHQRs were being intensively developed:

(1) A model with a film heater and a temperature sensor placed directly on the quartz blank [3-8], see Fig.2;
(2) A model "bulb in a bulb", where a quartz blank is mounted in the gas-filled internal bulb with a heater and a temperature sensor on the external surface of the internal bulb, and the space between the bulbs is evacuated [9], see Fig. 3.

0-7803-7688-9/03/$17.00 © 2003 IEEE

In both cases the following most serious problems were not overcome:

a. significant temperature gradients in ovenized unit of the holder and in the quartz blank being changed under the influence of the ambient temperature sharply worsened the frequency stability of IHQRs;
b. in a relatively short time vacuum in the IHQRs was broken and as a result the power consumption increased and the long-term frequency stability worsened.

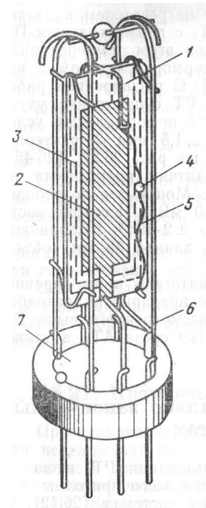

Fig.2 IHQR with a film heater and a temperature sensor on the quartz blank:

1 - quartz blank
2 - electrode
3 - film heater
4 - microthermistor-temperature sensor
5 - microthermistor's wires
6 - holder's post
7 - holder's base

In spite of the prolonged experimental work it did not succeed to create either model (1) or (2) that would meet the appropriate specifications in a wide temperature range. Then the works on IHQRs were stopped at the stage of the corresponding prototypes.

Principal advantages of the model (1), i.e. small overall dimensions and short warm-up time, attracted engineers' attention. Therefore this type of IHQRs at the beginning of the eighties was put in practice in Russia due to research of several investigators, mainly from Moscow Institute of Space Devices Engineering [8] and Omsk Institute of Instrument Engineering [10,11]. The industrial IHQR on frequency of 10 MHz with a film heater had warm-up time not more than 1.5 min and was designed in a miniature glass enclosure with the diameter of 10 mm (volume 3.5 cub. cm). Frequency stability with the external proportional thermocontroller was about $\pm 7 \cdot 10^{-8}$ over the range –10…+55°C.

In this IHQR practically all the heat flow emitted by the film heater goes directly through the quartz blank. Just this leads to appearing of temperature gradients in the blank and their change depending on ambient temperature. For this reason frequency stability sharply worsens if the temperature range becomes wider. In the industrial IHQR the quartz blank was mounted in a vertical direction (along the vertical axis of the glass enclosure). In order to decrease the thermal loss the parts of the holder are made as thin wires (diameter 0.2 … 0.4 mm) from low conductivity alloys (Ni-Cr alloy, constantan). As a result the design is characterized by low mechanical strength. The above stated impeded using such IHQRs in mobile systems.

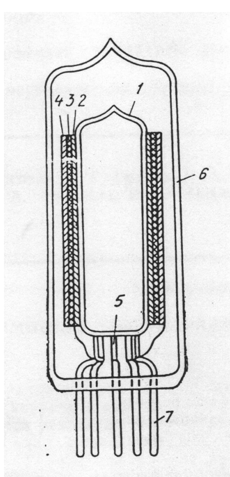

Fig. 3 IHQR of "bulb in a bulb" type:

1 - overnized crystal
2 - film temperature sensor
3 - thin-film dielectric
4 - heater
5 - crystal's wires
6 - vacuum glass bulb
7 - oven's wires

In 1972 research and development of IHQRs at Morion were started by a new team of Yakov Vorokhovsky, Inna Petrosyan, etc. Several inventions settled the following problems: establishing the uniform temperature field in ovenized unit of the holder and in the blank itself (1978), vacuum long-term stabilization (1979), ensuring the high strength to mechanical factors (1983); new industrial modification of SC-cut was created in 1987 (the so-called SV-cut), high short-term stability was provided for the oscillators (1991 – 1992). Actually the basic structure and technology were created being the basis of many industrial IHQRs and oscillators on their basis [12], see Fig. 4.

The idea of basic IHQRs' version (Fig. 4) is an isothermal chamber; on its bottom plate the positive temperature coefficient thermistor (posistor) heater and a temperature sensor are externally - mounted, and the quartz blank is internally-mounted. The chamber is an ovenized unit, which is evacuated together with the tube it is placed in. For vacuum stabilization the unspraying getter is used. For temperature frequency stability $5 \cdot 10^{-7}$ … $1 \cdot 10^{-6}$ the PTC-heater is used as a self-regulating one (without a separate sensor and thermocontrolling circuit). Just those IHQRs replaced in 1980 the above-described IHQRs with bimetallic thermostatic switch.

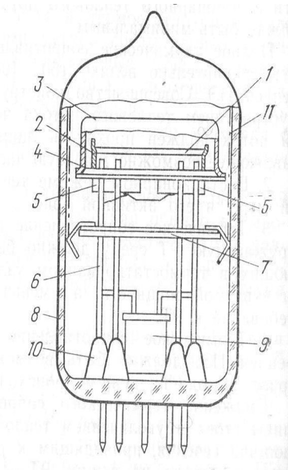

Fig. 4 IHQR with a posistor heater and a temperature sensor:
1 - quartz blank
2 - blank's posts
3 - cap (thermal screen)
4 - chamber's base
5 - heater and temperature sensor
6 - holder's posts
7 - fixing base with springs
8 - vacuum bulb
9 - unspraying getter
10 - bulb's base with pins
11 - thermal radiation screen

After creating the basic IHQR-structure with posistors it seemed logical to take the next step – to place an oscillator circuit made as a special IC inside the IHQR-enclosure and to overnize this IC together with the quartz blank. On the face of it such decision looked timely as a way to minimize the dimensions of the whole oscillator and to improve its frequency stability. This device was made and described in [13]. But in this device the ovenized IC emitting energy influences on the thermostatting temperature of the quartz blank and increases it by 10…20°C; the temperature increase worsens the quartz blank's long-term frequency stability. Additionally, the use of a glue to mount the IC on the holder led to a failure in keeping stable vacuum in the IHQR's enclosure and, consequently, - to the significant increase of long-term power consumption and worsening of frequency stability. So this idea was not developed and, all the more, was not realized in industrial manufacturing.

Successful engineering of a high stable quartz oscillator based on IHQR for the first time was considered in [14], and then with some corrections in [15]. Subsequently design and technology aspects of quartz oscillators on IHQRs were described in [16, 17]. Described in [16] IHQR actually represents substantial improvement of precision IHQRs. In this version the main element of frequency adjustment – the capacity diode – was installed into IHQR-structure. It was placed directly at the PTC-heater. Ovenizing of the capacity diode significantly improved frequency stability of the oscillator. Important possibilities in oscillator improving appeared when doubly rotated SC-cut blanks were used in IHQRs [17].

By 1996 – 1997 the following parameters had been achieved for industrial IHQR-based oscillators on frequencies 5…10 MHz:

- frequency stability vs. operating temperature ……..………………….. $\pm 1 \cdot 10^{-8}$;
- long-term stability per year ……………………………………………$\pm 5 \cdot 10^{-8}$;
- short-term stability (Allan Variance) per 1 sec……………...……..… $5 \cdot 10^{-12}$;
- phase noise at 1Hz from carrier …………………………………- 105 dBc/Hz;
- power consumption ………………………...……………………..….0.5 W;
- warm-up time for accuracy $\pm 1 \cdot 10^{-7}$ ………………………………..…2 min;
- volume…………………………...………………………… 50…65 cub.cm.

The developed IHQRs with PTC-heaters (without and with temperature sensors) and oscillators on them have been successfully used in control, navigation and telecom systems of many important projects including such as super-power launcher "ENERGIA", Space Shuttle "BURAN", satellite – retransmitters, SARSAT/COSPAS rescue beacons [18], air- and ship-board equipment, etc., etc.

The works are being intensively continued in the field of precision IHQRs and low noise oscillators on their basis.

Last year (2002) significant attention was directed for improvement of short-term stability [19]. The reasons for this were applications of corresponding OCXOs in different new Frequency/Time Standards (Cesiums and Hydrogen Masers). It was found that a PTC-sensor of IHQRs is the key source of short-term instability. Very significant improvements of short-term stability – up to $1\cdot10^{-12}$ (for 1 sec) – for industrial types of IHQR – based OCXO were achieved through replacement of the PTC-sensor by the glass-coated NTC-microsensor and through using of the 5 MHz SC-cut/3rd overtone blank.

One of the promising direction is the use of the 5th overtone SC-cut lenses in IHQRs. Testing of the oscillators' prototypes made with such 10 MHz IHQRs showed the Allan Variance per 1 sec ~ $1\cdot10^{-12}$. This is ~ 3 times better than for the 5th overtone of AT-cut. We plan to proceed with oscillators based on the 5th overtone SC-cut IHQRs.

In recent several years a new generation of IHQRs [20, 21] has been created. Their structure shown in Fig. 5 includes combined heater consisting of two parts:

(a) Thin film heater (as a "dynamic" heater) plated on the surface of the quartz blank. This is necessary to provide very short warm-up time,

(b) Heating transistor (as a "conservative" heater) is mounted on the blank's holder. This is necessary to guarantee high frequency stability.

The temperature sensor is mounted (glued) on the quartz blank and controls a thermocontroller that is located outside the IHQR.

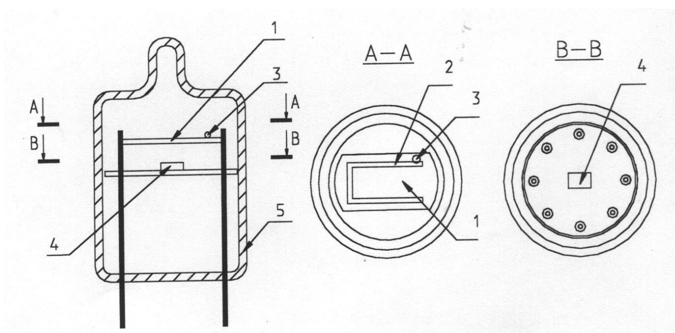

Fig. 5 IHQR with a combined heater:
1 - quartz blank
2 – thin film heater
3 - temperature sensor
4 - heating transistor
5 – glass vacuum bulb

During the warm-up period almost all power is being supplied to the film heater and heats the quartz blank very fast. Upon reaching the required temperature of the blank the heat emitted by the thin film heater reduces almost to a zero value and all power starts to be diffused by the transistor heater. Due to low amount of heat emitted by the film heater plated on the blank the temperature gradients on the blank itself are also very small. This allows achieving of acceptably high frequency stability in wide temperature range.

Oscillators based on this type of IHQRs with frequency stability better than $\pm5\cdot10^{-8}$vs. temperature of –60…+70°C and warm-up time of 30…45 seconds have been already developed and industrially manufactured. Such oscillators are being produced in 51x 41x 25 mm package with either 12V or 5V power supply and with steady state power consumption at the rate of <350 mW. For many applications the real advantage is also a very low current consumption after switching on, i.e. just 125 mA from 12V and 180 mA from 5V source.

At present, the works on the modification with high resistance against vibration and shocks are in progress; this will extend the forthcoming applications.

Further improvement of the IHQR design with combined heater assumes reduction of sizes with sustaining high frequency stability. The development of IHQR based oscillator in a package with dimensions 51x 41x 16 mm has entered its main stage. In this case IHQR is designed in a vacuum sealed glass enclosure having the diameter of 13 mm.

Research and development of improved devices are continued; new models are put into production line. Different types of IHQRs and oscillators on them manufactured at Morion are well-known in Russia and during the last years many customers outside Russia have become familiar with these products.

Reference

1. Б.Г.Преображенский, С.К.Ященков. Кварцедержатель для термостатируемых пьезокварцевых элементов: Авт. св. СССР, кл. $21a^4$ 10, №135296, приоритет 6.05.1960, опубл. БИ, 1961, № 2.
2. Б.Г.Преображенский. Кварцедержатель для термостатируемых пьезокварцевых элементов: Авт. св. СССР, кл. $21a^4$ 10, №191247, приоритет 10.11.1964, опубл. БИ, 1967, № 3.
3. П.Г.Поздняков, Э.Г.Маркосян. Пьезоэлектрический резонатор с нагревательным элементом: Авт. св. СССР, кл. $21a^4$ 10, №166745, приоритет 12.03.1963, опубл. БИ, 1964, № 23
4. Thermally Stabilized Crystal Units: Pat. USA 3201621, Nat. cl. 310-89. Consuelo Stokes Milner, Hollis. – Filed Mar. 18, 1963, Pub. Aug. 17, 1965.
5. Quartz Crystal Temperature Control: Pat. GB 1062059, Int. cl. H03H 9/18, G05D, H05H. D. Kerr. - Filed July 8, 1964; Pub. March 15, 1967.
6. Internally Heated Crystal Devices: Pat. USA 3431392, Int. cl. H05B 3/06. W.J.Garland, L.J.Hassencahl, D.D.Lenhart, G. Wolfe. - Filed Jan. 13, 1967, Pab. Mar. 4, 1969.
7. F.G.Tinta, A.S.Matistic, G.A.Lagasse. The Direct Temperature Control of Quartz Crystals in Evacuated Enclosures: Proc. 24th ASFC. – Atlantic City, N. J., 1970. - pp.157-167.
8. П.Г.Поздняков, И.М.Федотов, В.И.Бирюков. Кварцевые резонаторы с пленочными нагревателями//Электронная техника. Сер. IX. – М., 1971. - Вып. 4. - с. 27-37.
9. С.И.Лассовик, Г.Г.Грачев, Н.И.Сизов и др. Термостат для кварцевых резонаторов: Авт. св. СССР, кл. G 05D 23/30, №391544, приоритет 12.07.1971, опубл. БИ, 1973, № 31.
10. В.С.Теренько, В.П.Багаев. Влияние локального нагрева на частоту круглых пьезоэлементов с колебаниями сдвига по толщине //Электронная техника. Сер. 5. – М., 1978. - Вып. 1(26). - с. 34-37.
11. А.А.Иванов, В.С.Теренько, В.Г.Тихомиров. Кварцевый резонатор-термостат с прямым термостатированием пьезоэлемента//Электронная техника. Сер. 5. – М., 1983. - Вып. 1(50). - с. 76-78.

12. Я.Л.Вороховский. Резонаторы-термостаты и пьезоэлектронные устройства на их основе//Пьезоэлектрические резонаторы: Справочник. - М.: «Радио и связь», 1992. - Раздел 26.- с. 318-386.
13. А.А.Волков, Я.Л.Вороховский, А.В.Гробов и др. Термостат для кварцевых резонаторов: Авт. св. СССР, кл. G05D 23/30, №555386, приоритет 20.11.1975, опубл. БИ, 1977, №15.
14. А.Д.Чернядьев, С.И.Лассовик, Г.Б.Альтшуллер. Проектирование экономичных высокостабильных кварцевых генераторов на резонаторах-термостатах//Техника средств связи. Сер. ТРС. – М., 1978. - Вып. 4(20). - с. 150-158.
15. Г.Б. Альтшуллер, Н.Н. Елфимов, В.Г.Шакулин. Кварцевые генераторы: Справочное пособие. - М.: Радио и связь, 1984. - 232с.
16. А.А.Волков, Я.Л.Вороховский, Б.Г.Драхлис и др. Построение высокостабильных экономичных малогабаритных кварцевых генераторов с малым временем установления частоты на резонаторах-термостатах//Электронная техника. Сер. 5. – М., 1987. - Вып. 4(69). - с. 59-64
17. Ya.L.Vorokhovsky, B.G.Drakhlis. High-stability quartz oscillators on internally heated quartz resonators with AT and SC cuts: Proc. of the 45th ASFC, Los Angeles (CA). – USA, 1991. - pp. 447-451.
18. Ya.L.Vorokhovsky, I.G.Petrosian, B.G. Drakhlis, A.A.Volkov. High-stability quartz oscillators for SARSAT/COSPAS project and other satellite-based global positioning systems: Proc. of the 7th European Frequency and Time Forum. - Neuchatel, Switzerland, 1993. - pp.315-318.
19. Ya.L.Vorokhovsky, S.V.Anastasyev, A.A.Volkov. The significant improvement of basic OCXO for time and frequency standards: Proc. of the 17th European Frequency and Time Forum and 2003 IEEE International Frequency Control Symposium. - Tampa, May 2003.
20. И.В. Абрамзон. Кварцевый резонатор-термостат: Пат. РФ, кл. 6 H03H 9/19, №2101854, приоритет 12.01.1996, опубл. 10.01.1998.
21. И.Г.Петросян. Кварцевый резонатор с внутренним термостатированием: Пат. РФ, кл. H03H 9/19, H03H 9/15, №2155442, приоритет 04.06.1999, опубл. 27.08.2000. Патентообладатель ОАО «Морион»

Dr. Yakov L. Vorokhovsky, Inna G. Petrosyan, Alexander A. Volkov
Morion, Inc.
13a KIMa Avenue, St.Petersburg, 199155, Russia,
Tel +7 812 350-7572, Fax +7 812 350-7290
E-mail: yakov@morion.com.ru