Vrempa-CH
RUSSIA

6th International Symposium “METROLOGY OF TIME AND SPACE"

PASSIVE HYDROGEN MASER – PROSPECTIVE GLONASS SATELLITE CLOCKS

Belyaev A.[1], **Medvedev S.**[1], **A. Myasnikov**[2], **Pavlenko Y.**[1], **Sakharov B.**[1], **Smirnov P.**[1], **Storojev E.**[1], **Tulyakov A.**[2]

[1]*«Vremya-CH», Nizhny Novgorod, Russia*
[2]*«Russian Institute of Radionavigation and Time (RIRT)», St-Petersburg, Russia*

Introduction

The new space atomic clock, developed by “Vremya-CH” JSC is intended for GNSS GLONASS.

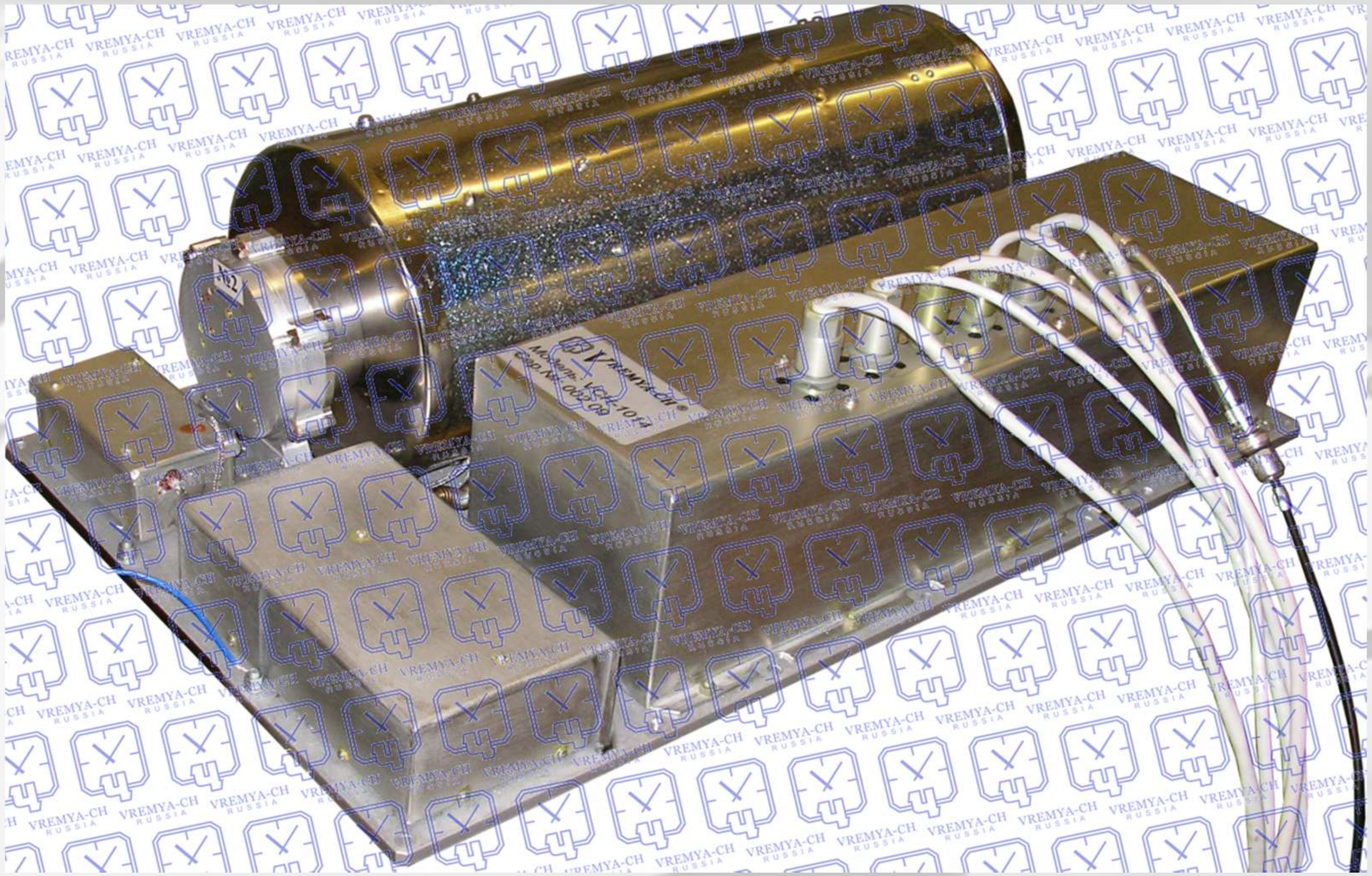
Third generation of GLONASS satellites, GLONASS-K, peculiarities:

- ✓ Nonhermetic construction
- ✓ Longer lifespan
- ✓ Additional navigation CDMA signals, compatible with GPS/Galileo/Compass
- ✓ Better accuracy

Features of the clock:

- ✓ Passive hydrogen maser technology
- ✓ Unpressurised construction
- ✓ Short term stability 7×10^{-13} @1s, long term stability 5×10^{-15} @1 day
- ✓ Operational lifetime more than 10 years

Construction



General view of Engineering Model of the maser

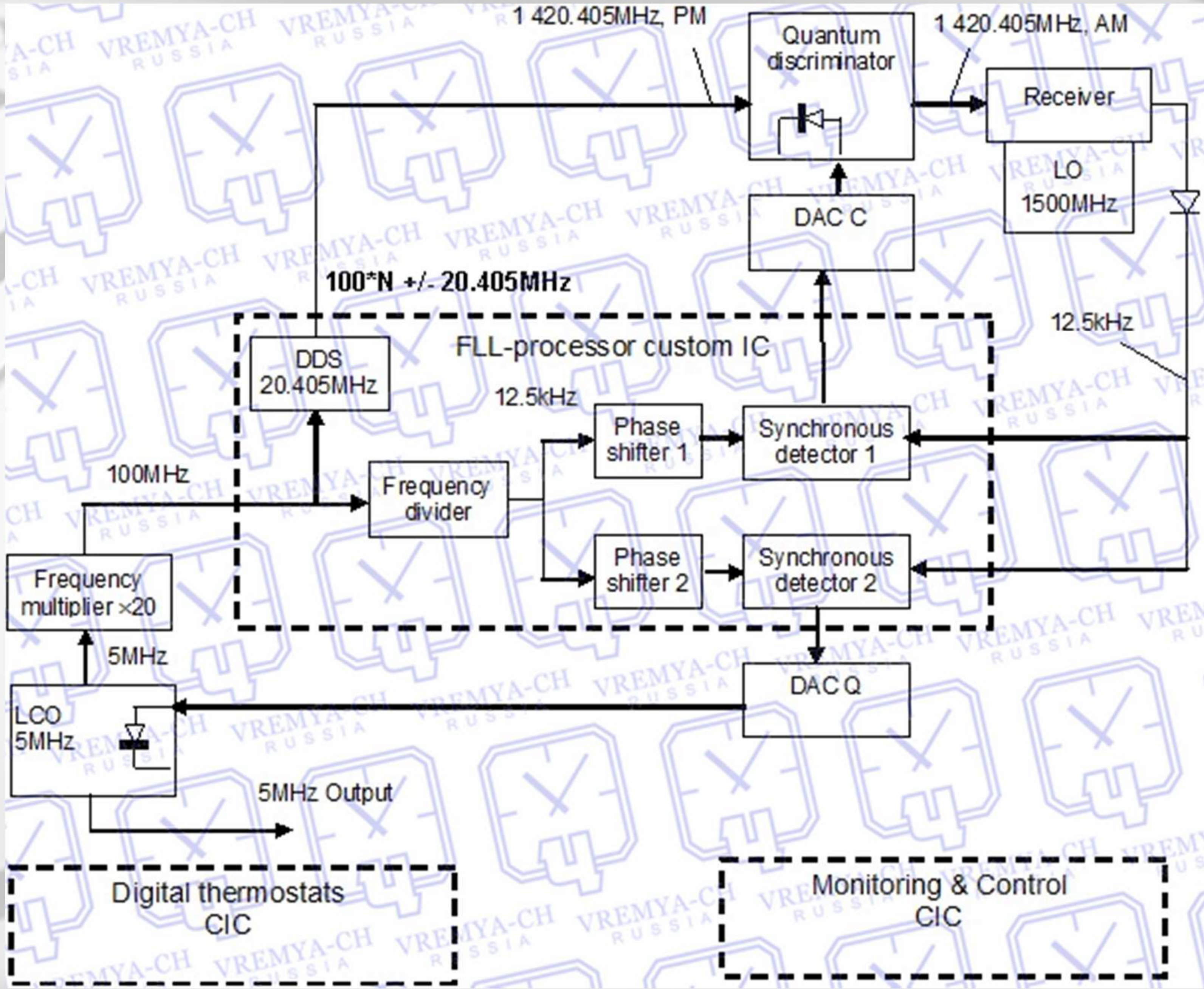
Two main parts of the maser – a physical package and an electronic unit – are placed on thermostabilized plate. The weight: physical package - 11,4 kg; electronic unit – 4,7 kg ; plate – 4,5 kg; total – 20,6 kg. Needed temperature accuracy – not more than ±1 ºC in any point of working temperature range from 15 to 30 ºC. Maximum allowed temperature rate is ±0.2 ºC in 30 minutes

Construction features

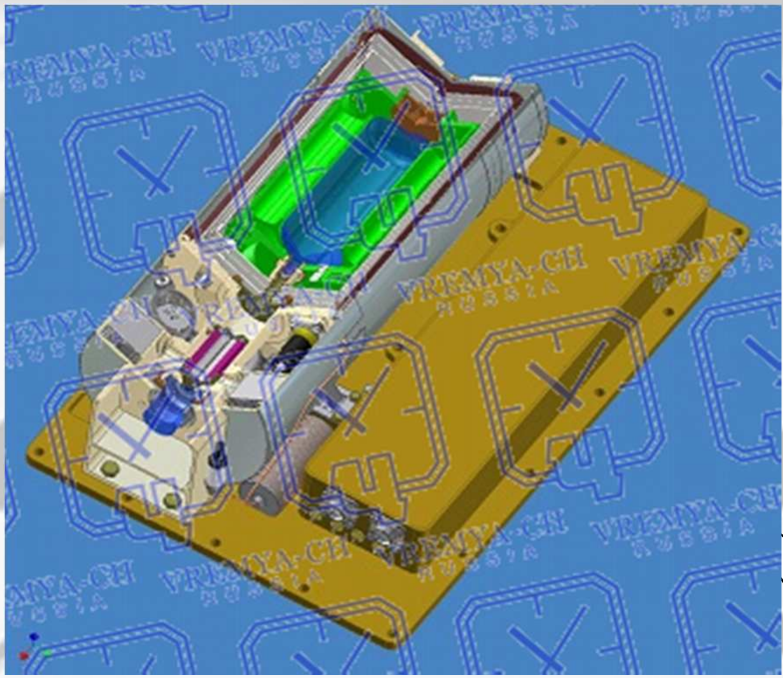
- ✓Aluminum magnetronic cavity
- ✓Quartz storage bulb in volume of 0.4 liters, covered on the inside by radiation hardened Teflon F10
- ✓Four magnetic shields
- ✓Loaded Q-factor of copper-plated cavity is equal to 9000
- ✓Temperature coefficient – 15 kHz/ ºC
- ✓The varicap tuning range – 200 kHz
- ✓Hydrogen line wideband < 2 Hz
- ✓Maser gain – 3.5 dB (5-7 dB @ low signal)
- ✓LaNi5-based hydrogen source capacity – 3.6 g or 40 liters of molecular hydrogen (at 20 ºC and 1 bar)
- ✓Consumption of hydrogen – 1.5 ÷ 2 bar*liter/year

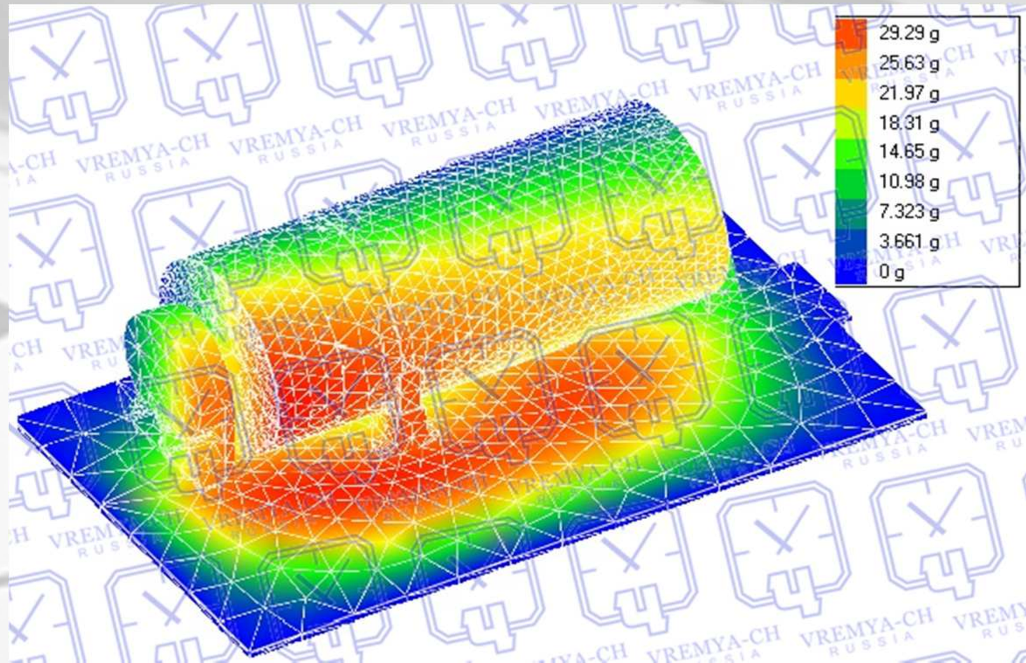
Vremya-CH
RUSSIA

Diagram of the electronic unit



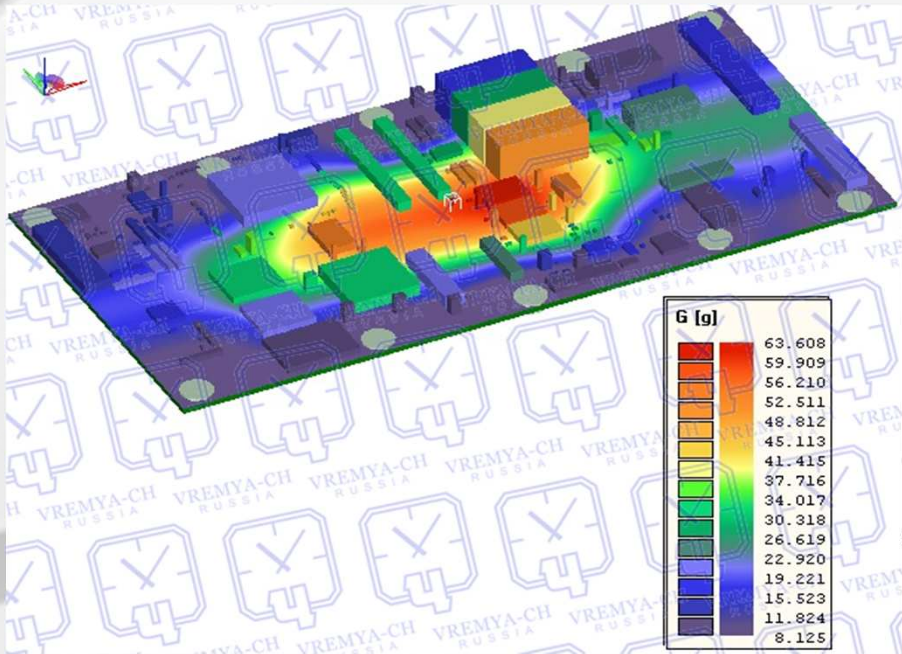
Mathematical modelling





Field of maximal accelerations. Blow along axis Y by duration 2 milliseconds and amplitude 150 g

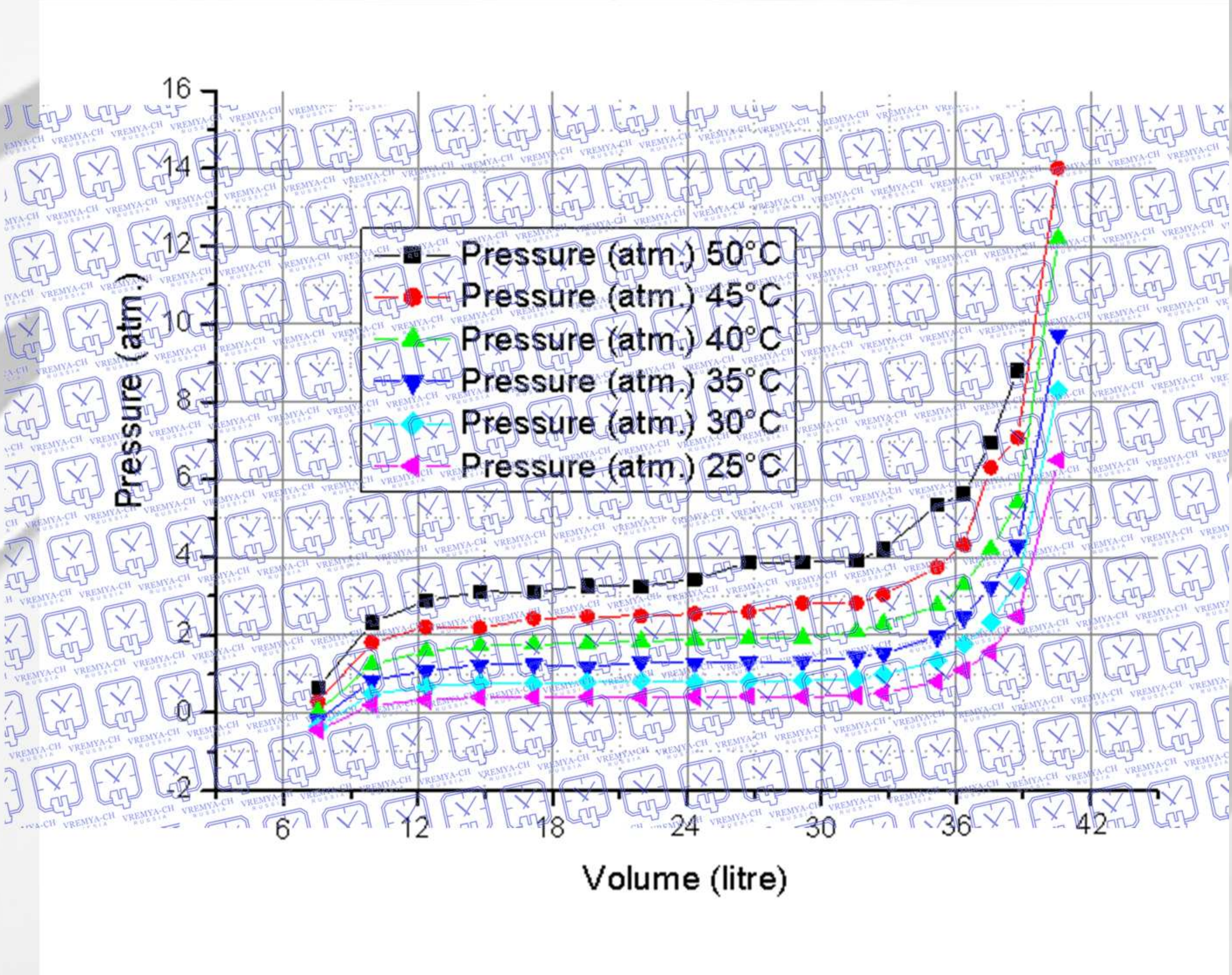
3D ANSYS mechanical simulation model (17431 elements and 33447 nodes)



Field of maximal accelerations on sinusoidal vibration

Vrema-CH
RUSSIA

Experimental investigation of the hydrogen source

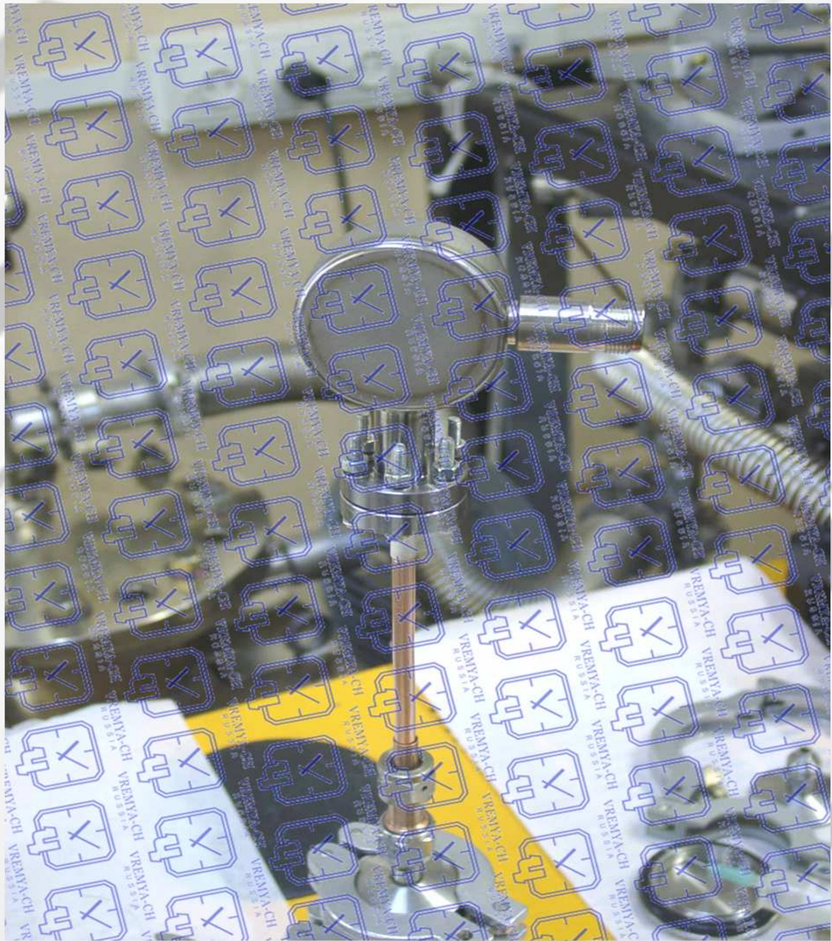


Empirical formula

$$V_{H2} = \frac{(P_{H2} - 1{,}7852) \cdot V_{init}}{1{,}3285}$$

Pressure in LaNi5-based hydrogen source depending on volume of the reserved hydrogen and temperature

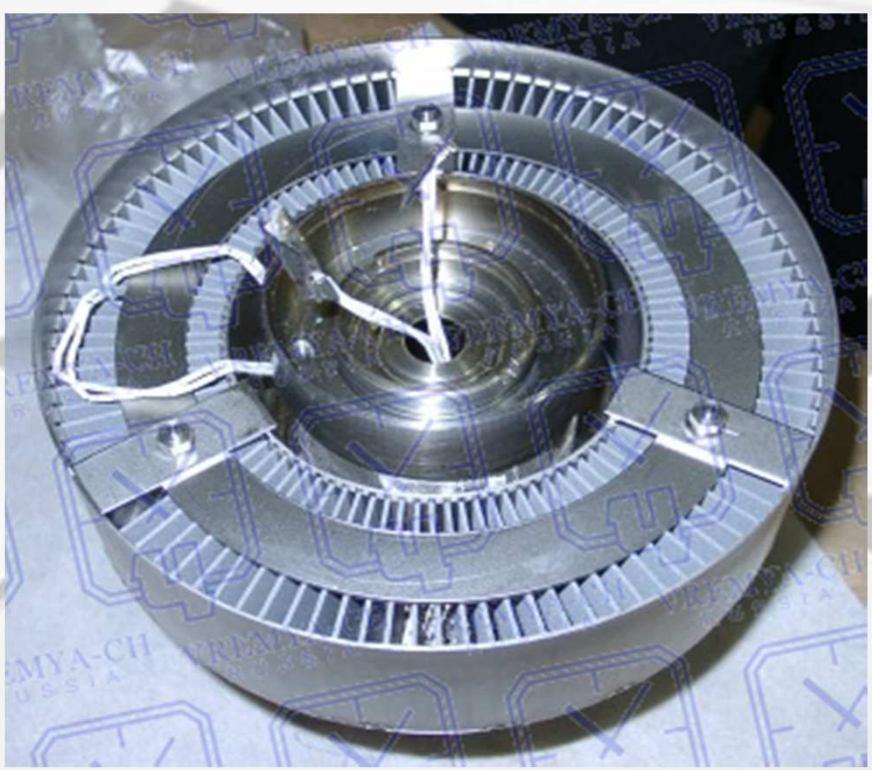
Experimental investigation of the pumping system



Ion pump

Getter pump sorbtion ability test bench

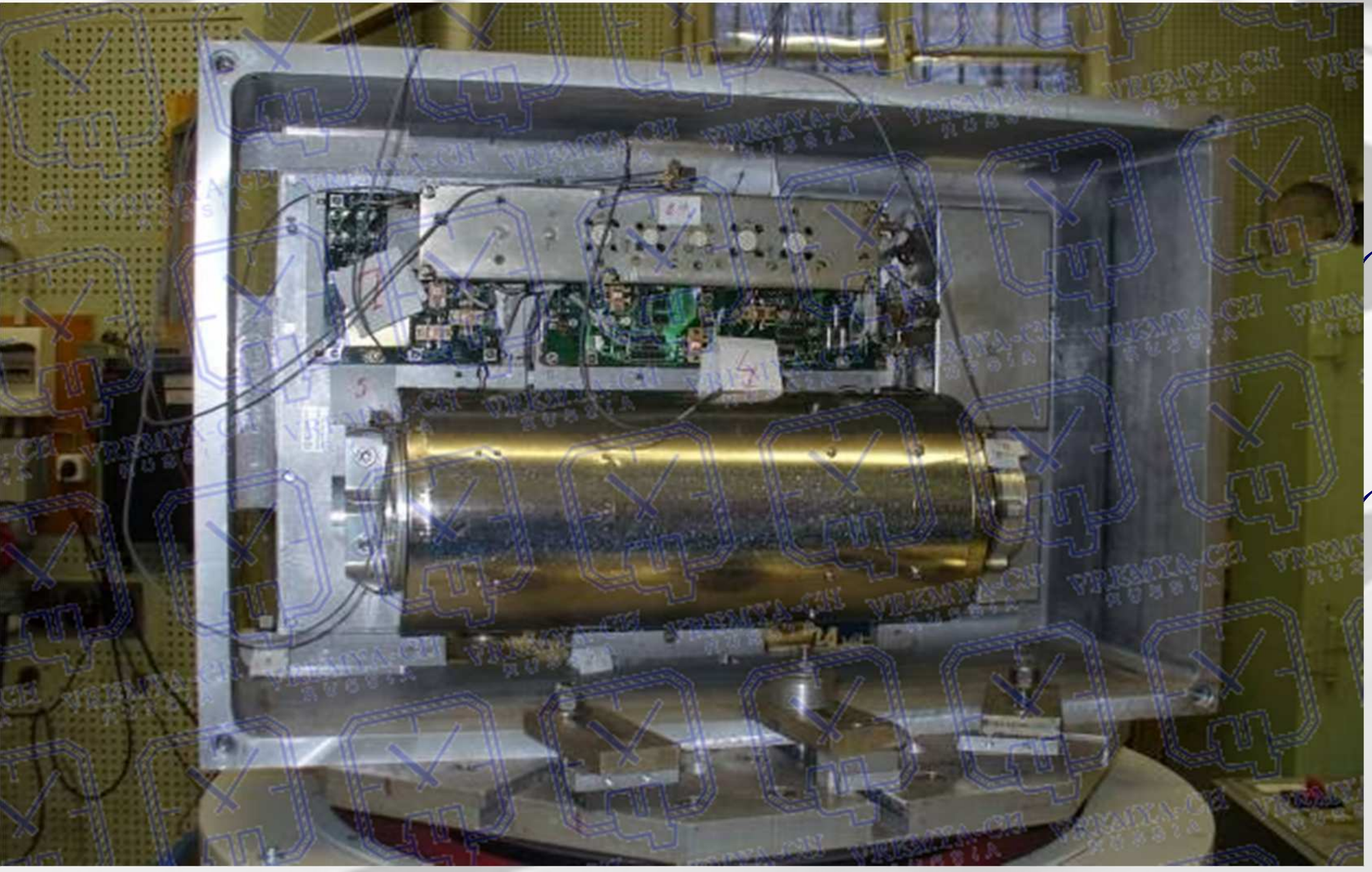
Experimental investigation of the getter pump



Getter pump

Getter pump after 52 bar*liter hydrogen absorption (corresponds to 20 years operation)

Testing on a vibration table



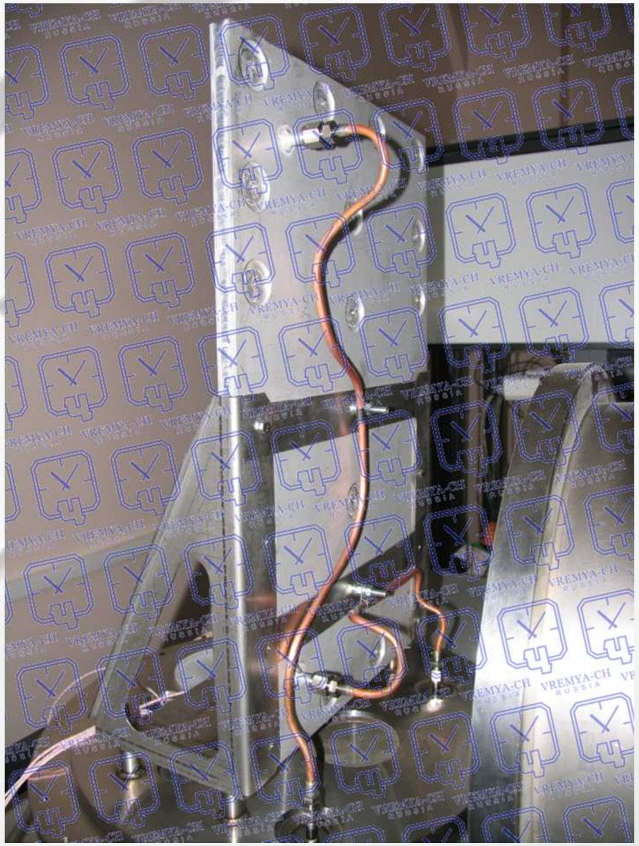
Maser in special adaptation on a vibration table

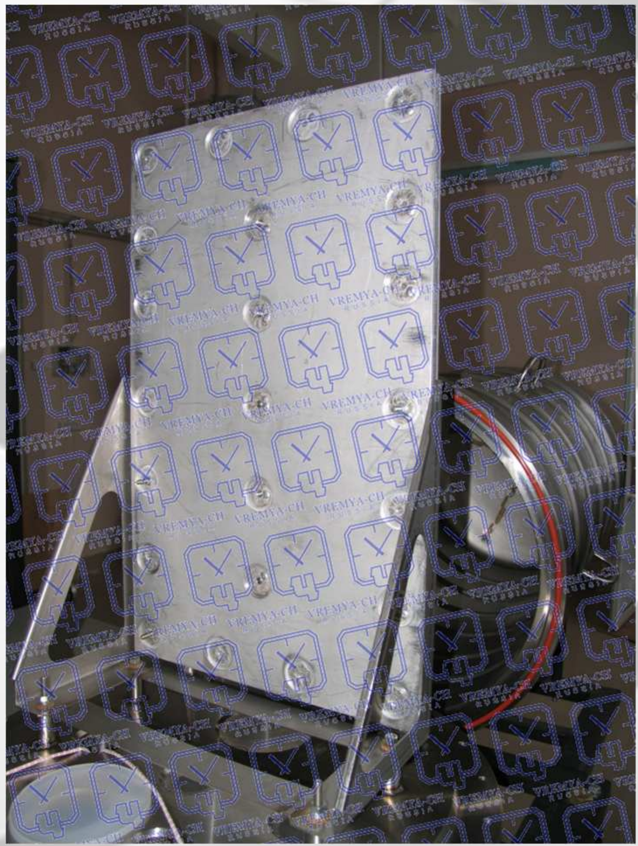
- **Broadband random vibration in a range 20 – 2000 Hz with vibroacceleration up to 10 g**
- **Shocks with amplitude up to 150 g at duration 2 ms**

Lifetime test bench

Vremya-CH
RUSSIA

System of thermo stabilization



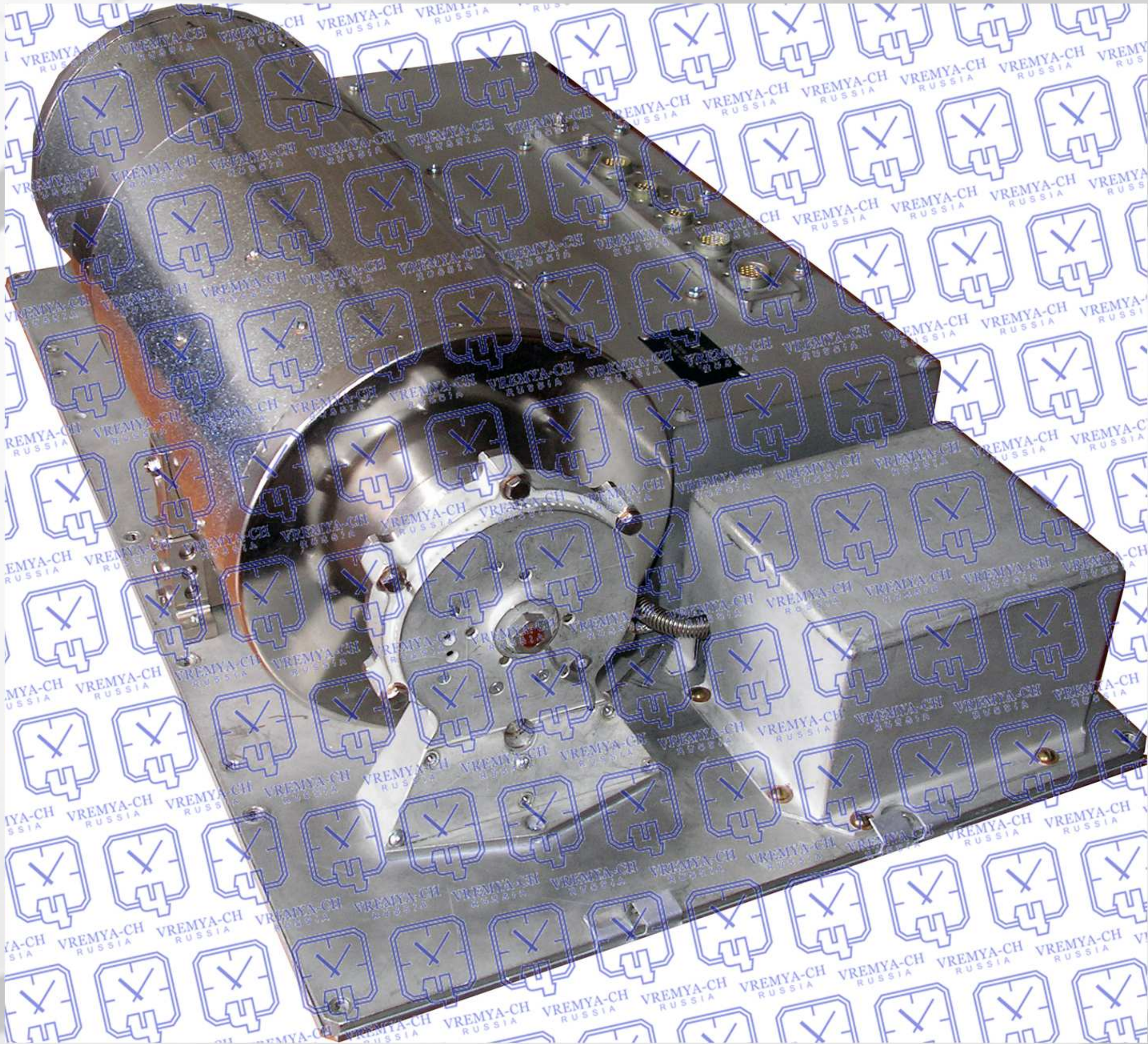


Thermostbilized plate

Chiller HRS-12

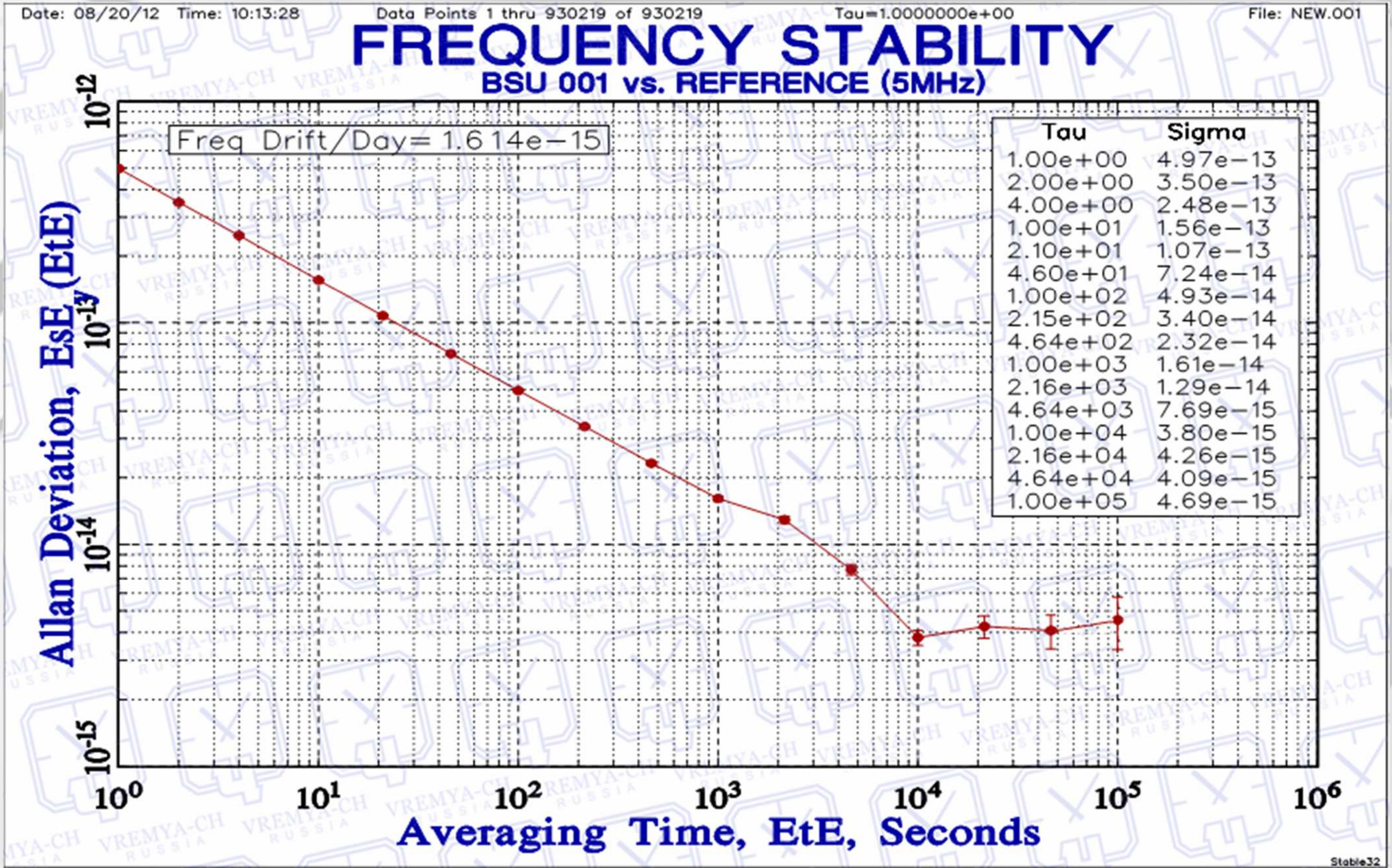
Vremya-CH
RUSSIA

Flight Model



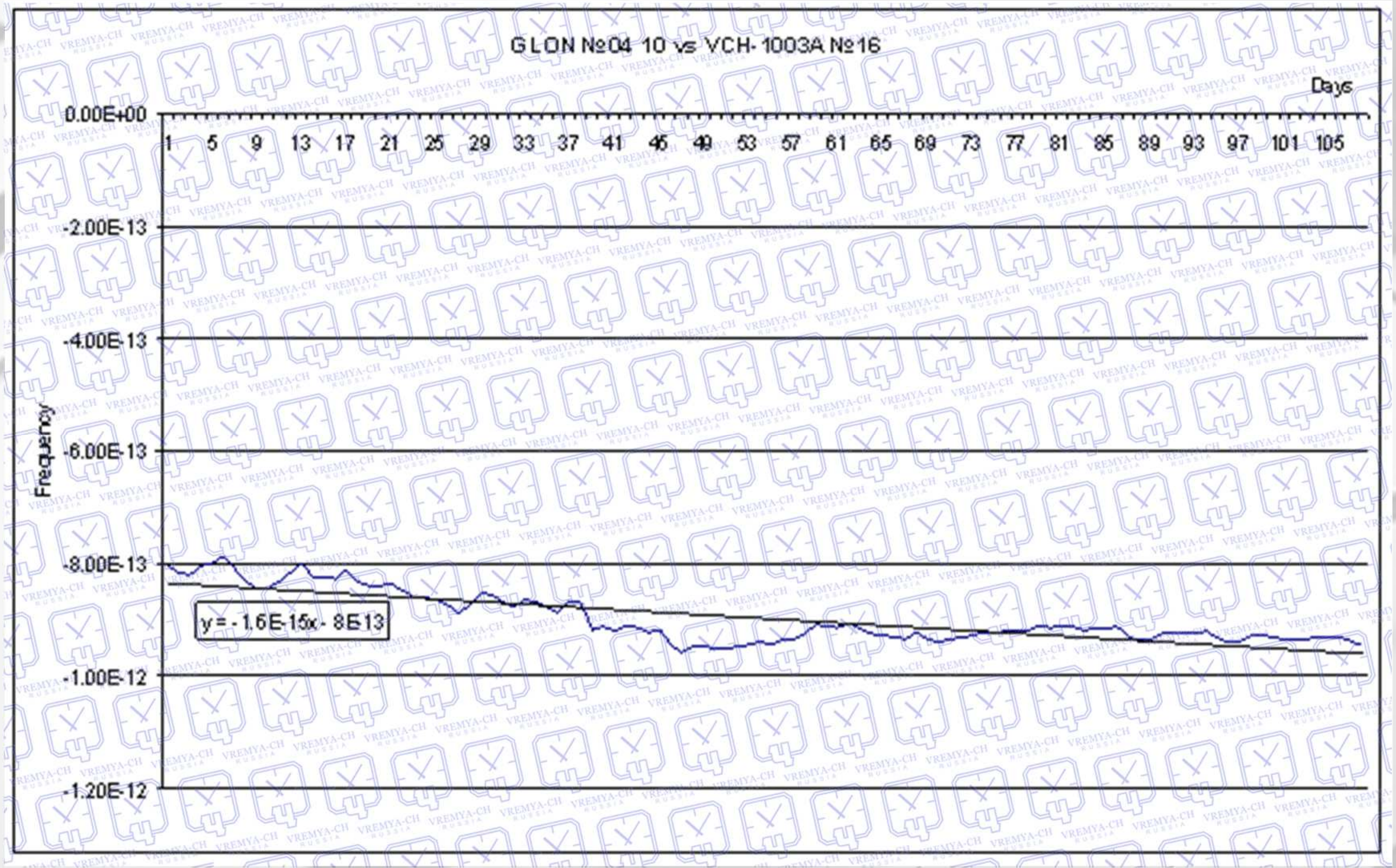
General view of Flight Model of the space clock

Frequency stability



Tau	Sigma
1.00e+00	4.97e−13
2.00e+00	3.50e−13
4.00e+00	2.48e−13
1.00e+01	1.56e−13
2.10e+01	1.07e−13
4.60e+01	7.24e−14
1.00e+02	4.93e−14
2.15e+02	3.40e−14
4.64e+02	2.32e−14
1.00e+03	1.61e−14
2.16e+03	1.29e−14
4.64e+03	7.69e−15
1.00e+04	3.80e−15
2.16e+04	4.26e−15
4.64e+04	4.09e−15
1.00e+05	4.69e−15

Frequency stability



One day averaged frequency

Specification

Parameter	Requirements	Measurement
Output signal frequency	5 MHz	5 MHz
Frequency instability (Allan variance) 1 s 100 s 1 hour 1 day	 7×10^{-13} 7×10^{-14} 2×10^{-14} 5×10^{-15}	 5×10^{-13} 5×10^{-14} 1×10^{-14} 5×10^{-15}
Frequency drift per day	1×10^{-14}	1.6×10^{-15}
Thermal sensitivity (1/°C)	5×10^{-15}	4.7×10^{-15}
Magnetic sensitivity (1/Gauss)	1×10^{-14}	9×10^{-15}
Power consumption	50 W	50 W
Mass	25 kg	22,4 kg
Lifetime	More than 10 years	

Conclusion

The new space atomic clock for GNSS GLONASS has been developed by “Vremya-CH” JSC.

Features of the clock:

- ✓ Passive hydrogen maser technology
- ✓ Unpressurised construction
- ✓ Short term stability 7×10^{-13} @1s, long term stability 5×10^{-15} @1 day
- ✓ Operational lifetime more than 10 years

Possibilities of the further improvement passive hydrogen maser:

1. Reduction in weight up to 18 kg;
2. Improvement short-term stability to 3.5×10^{-13} @1s, long-term stability to 2×10^{-15} @ 1day;
3. Increase of reliability due to of considerable improvement of a condition of discharge excitation in the bulb (know-how).

Thank you!