The Compensation and Processing Techniques Used for Rubidium Frequency Standards*

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Abstract： The rubidium frequency standards as a practical standard always is affected by Drift due to temperature, Drift due to aging, phase noise, and so on, from the system. In most cases the specifications can be met by improvement of physics package and electronic circuit. Recently we has developed some compensation and processing techniques may be suitable for the performance improvement of rubidium frequency standards. A 5.3125MHz DDS controlled by CPU is inserted as the synthesizer of the frequency standard to compensate the different system influences, and the quantized error can be decreased obviously. In order to improve the short-term stability and phase noise of the frequency standard， the control signal of VCOCXO is corrected by Kalman filter arithmetic and unreal control approach. Some basic experiments have been done and the stability of the rubidium (Rb) frequency is improved.

I. INTRODUCTION

The stability and accuracy of atomic frequency standards are the key research for atomic frequency standard. Major influencing factors concerning stability and accuracy of atomic frequency standard are linewidth and stability of spectral line, Signal noise ratio (SNR) of servo system and the effect of environment. Environmental interference of the atomic energy level and various effects about atomic and molecule movement is the trouble root of accuracy of the spectral line. The stability depends on the variety relation of those factors with time [1]. Typically, the improvement of the physics package is the available method to advance the stability of the atomic frequency standard. A lot of research work has been carried out in the field in recent years [2] [3].

The Further development is not only by the physics package, but also by the electronic circuit, and the same purpose can reach. Digital circuit has good anti-interference，add valid intelligent processing can help to improve the stability of the atomic frequency

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standard and compensate drift due to temperature and aging which is difficult for the physics package to deal with alone.

II. THE PERFORMANCE OF ATOMIC FREQUENCY STANDARD ANALYSIS AND IMPROVEMENT TECHNIQUE

Atomic frequency standard can be taken as a PLL system with high stability VCOCXO. Generally, SC cut crystal oscillator itself has certain holding property of frequency stability in short-term. The long-term stability and accuracy of passive atomic frequency standard are high, but its short-term stability and phase noise are not as good as the adopted internal VCOCXO. Because noise is introduced by the servo system, the phase noise is lower than that of internal VCOCXO. Suitable non real-time processing is taken, and corresponding longer time-constant of the physics package is used to control the long-term performances of the VCOCXO [4]. According to mathematic model and noise feature from output of the physics package, then optimal linear time-domain filtering, Kalman filter, to the output of the physics package could be realized on the basis of historic datum under the criterion of least mean square error.

High accuracy frequency signal and some noise signals with second order derivative of steady ergodicity are included in the error correction output signal of physics package of the passive Rb frequency standard [5]. Kalman filter can be use to filter those noise and get optimal estimate. If Kalman filter running time and sample data get enough, high precision estimate of frequency drift rate can be realized, and better filtering effect can also be gotten. This method can improve its anti-interference performance, then non real-time control algorithm and PID algorithm of adjustable time-constant is taken. Overshoot is be avoided by reasonable distribution of the real time control quantity with the time extend, and the frequency stability of the OCXO can be corrected from the whole historic data. The front PID can process control quantity with damping calculation to eliminate excessive control quantity, which make sure the control quantity is adjustable and non real-time, so real-time control quantity is acted on OCXO for several times. Control time-constant should be increased as long as possible under required accuracy, which can improve the fineness and reduce overshoot of the control. The short-time stability and phase noise of the output of the OCXO can be improved and accuracy of the output can be kept in a short term.

The drift rate of Rb atomic frequency standard is obviously monotonic variation, therefore, it is completely feasible to compensate based on the operation time of frequency standard. The tested data which is obtained from several tens of Rb atomic frequency standards about more than two years for drift rate is shown as fig.1. The drift rate of Rb atomic frequency standard is not totally linear. Influence of one order term can be compensated in the proper method. And further study, influence of some high order terms can be compensated. Initial drift rate is relatively big, after that entering into flat region. The aging rate of the frequency standard is gradually decreased with operated time. Different frequency standards have different aging rate data.

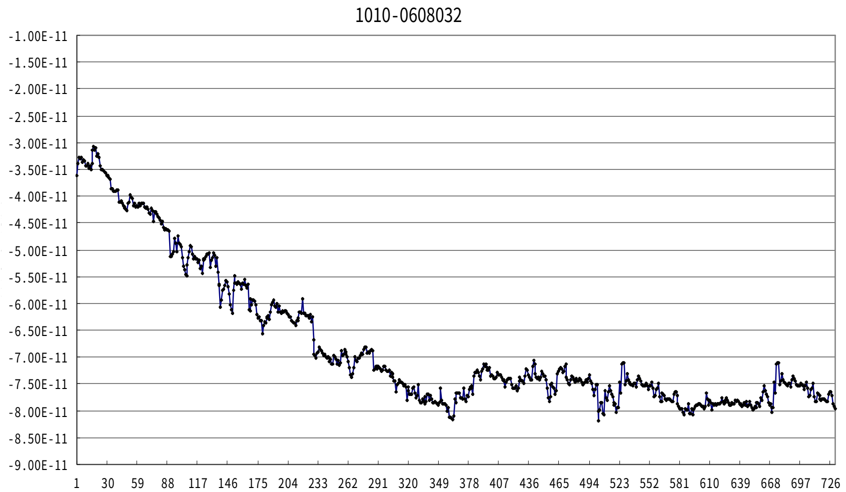

Fig. 1. Drift rate curve of a XHTF1010 0608032 Rb frequency standard form July 2007 to July 2009

For frequency standard, the influence of temperature is usually bigger than drift rate. So the control signal is a function of temperature with time and aging rate. Influence of ageing to frequency is a linear function of time, while the influence of temperature is discrete for different frequency sources. Various elements should be considered， and drift rate and corresponding coefficients of temperature characteristic curve can be figured out. The output of frequency source still varies with time and temperature even in the basically stable parameter. Data update and support based on comparison and measurement is also necessary.

Temperature-frequency characteristic with good repeatability is system errors [6]. The temperature compensation techniques under the digital circuitry for the OCXO is used to process atomic frequency standard, temperature characteristics of 10^{-12} in a wide temperature range can be attained. In order to limit quantization error caused by digital compensation technique, DDS and the multiplication of locked system is be used to improve compensation fineness obviously. For influence of temperature changes slowly, non real-time algorithm, relationship of temperature and noise should be considered in time.

III. EXPERIMENTS AND ANALYSIS

We have done some experiments on the domestic Rubidium frequency standard. The block diagram of the experiment system is shown as fig.2.

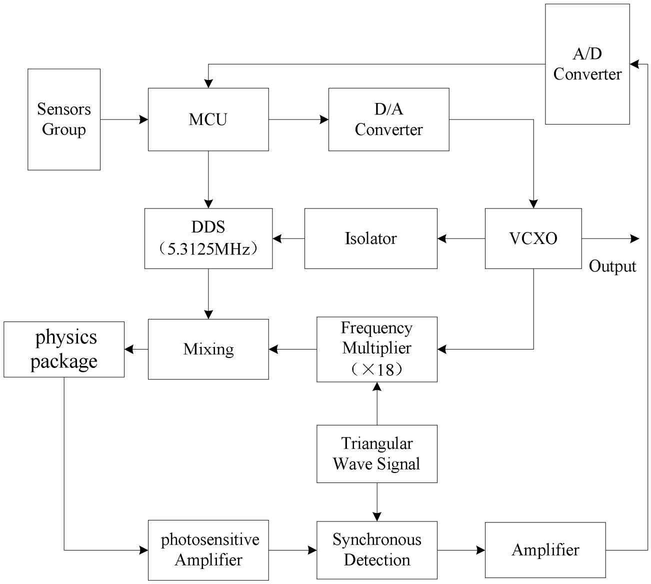

Fig. 2. The figure gives the block diagram of Rb frequency standard digital and intelligent process with multiplication

The adjustment of the 6834.6875MHz excitation signal is from the fine-adjustment of the 5.3125MHz part frequency generated by a DDS, so the system exist multiplication effect of 3 orders (5.3125/6834.6875). The regulation of the10MHz signal output of the atomic frequency standard can reach μHz. Now the adjustment resolution of the DDS can reach milli-hertz or better [7]. Based on the experimental, the stability of the DDS can reach $1\sim2\times10^{-11}$/s when higher stability frequency standard is adopted. But it will be better in a narrow frequency range. For the 10MHz nominal output, the adjustment resolution of the DDS can be ensured effectively. The stability of the frequency standard has been improved. At the same time, the short-term stability and phase noise level of Rubidium frequency standard are also better than before, short-term stability is $< 2\times10^{-12}$/s. Phase noise is improved about 10~15dBc/Hz at 1Hz and 10Hz respectively which is shown as Fig.3.

IV. Conclusion

It can solve many practice problems when the digital process and intelligent process in atomic frequency standard is taken, such as improvements of short-term stability, phase noise, drift due to aging and so on. Meanwhile, the system errors such as aging rate and temperature-frequency characteristic can also be corrected according to corresponding variation. Furthermore, performance of atomic frequency standard can be improved by intelligent process algorithms and the non-real time control, it is essential that the external frequency source has an equally low phase noise output as the internal oscillator and better short-term stability can be obtained.

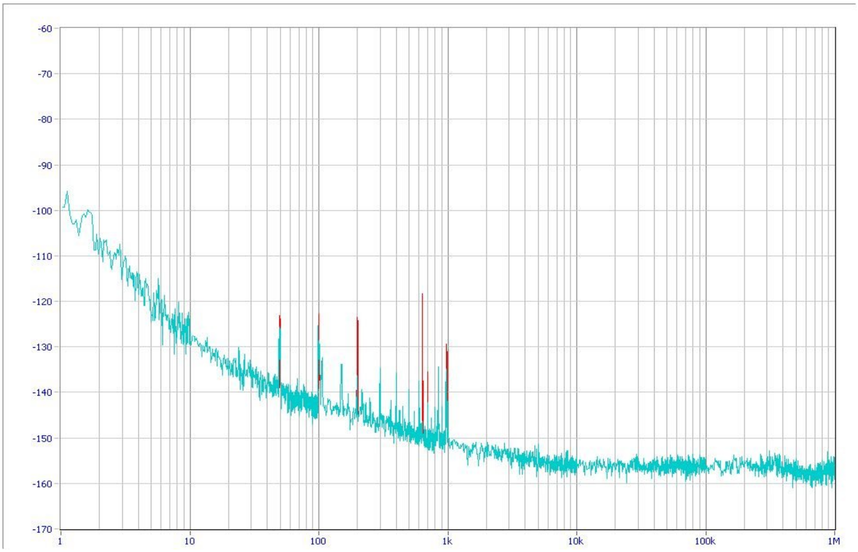

Fig. 3. The curve improved of phase noise based on Rb atomic frequency standard.

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