RELATION BETWEEN PHYSICAL PROCESSES AND AGING

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***Abstract*— An analysis of the main effects of crystal and oscillator aging and the first results of calculations will be shown. The summary of different time functions with different time constants were used for approximation of the experimental data.**

I. INTRODUCTION

A way for a better prediction of the aging behaviour of quartz crystals and crystal oscillators was searched. Therefore a literature survey was done and analysed to find a way for the prediction (see Literature list). Normally only one or two logarithmic terms are used to describe the aging behaviour. But there exist also effects with non logarithmic behaviour over time.

Aging is a function of temperature, time, process parameters and used materials. The different aging reasons have different time and temperature dependencies, means different approximation functions describe the behaviour.

For a constant production process and a constant aging temperature it should be possible to find a set of functions with according time constants to fit the experimental data. Each part of the aging function and therefore each time constant should be connected with only one physical or chemical process in the quartz crystal. It is important to find the connections between the production steps and the influenced time constant and function.

The time constants should be the same for all manufacturers and all process runs. Only the amplitude of the function can change. Such a tool could be very helpful for production control and also for incoming inspection of crystals and oscillators.

II. MATHEMATICAL METHOD

There are three types of function used to describe the different physical (and chemical) processes.

- a set of parabolic functions $a \times time^{b}$
  For diffusion effects
- a set of exponential functions $a \times e^{b \times time}$
  For chemical reactions, adsorption and desorption effects
- a set of logarithmic functions $a \times \ln(b \times time)$
  For chemical and stress effects

Since for one type of function can exist more than one effect, a summation of four functions for each type was selected (see equation 1).

Equation 1

$$Aging(time, T = const) = \sum_{n=1}^{4} a_n \times t^{b_n} + \sum_{m=1}^{4} a_m \times e^{b_m \times t} + \sum_{o=1}^{4} a_o \times \ln(b_o \times t) \quad [1]$$

$t \rightarrow time$
$T \rightarrow temperature$
$1/b \rightarrow decaytime$

The mean square method was used to build a useful function to determine the coefficients. This function was solved by a quasi Newton approximation in the 28 dimensional room.
The results of this approximation, calculated over several hundreds of crystals, show a set of stable time constants (b). The used measured aging values cover a time of 5 years. The variants are in the range of 10 to 15%. The calculated values for very high decay times have clearly a bigger error. There are two sets of decay times. One set is exists in all crystals independent on design and a second set is depend on the crystal design (see Table 1).

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Table 1 Decay times

Not design related		
Function	**Decay time [day]**	**Related effect**
parabolic	816	Diffusion
exponential	110	Adsorption
Design related		
Function	**Decay time [day]**	**Related effect**
parabolic	5	Diffusion ?
	3	
	2	
	1,5	
exponential	28	Adsorption
	6,5	
	4	
	2,5	
logarithmic	75	Stress release
	30	
	20	
	15	
	12	

III. CRYSTAL AND OSCILLATOR

The determination of the time constants was done in the first step for the crystal. To divide the effects of crystal and oscillator it is necessary to compare the time constants of crystals with the time constants of crystals in an oscillator. A known effect is the change of the aging behaviour coming from the oscillator. We measure the aging of a crystal for a time period, than measure the same crystal in an oscillator for a time and after this procedure control the passive aging again. In this case we will find that the passive aging curves fit together. The gradient of the oscillator aging curve strongly depends on the oscillator design. We can find zero or plus or minus changes in the gradient of the oscillator aging curve compared with the passive aging (fig 1).

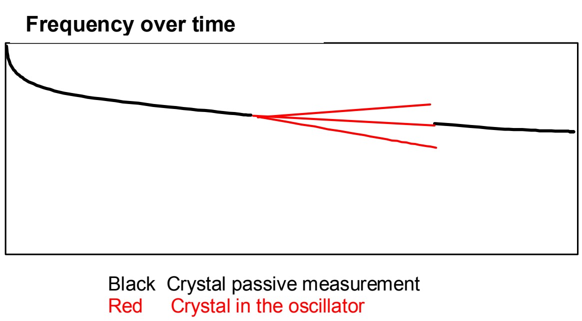

Figure 1 Frequency aging of a crystal passive in compartment with the aging in different types of oscillators

IV. DESIGN DEPENDENCY

The size of the vibrating area in relation to the surface is depend on the design and the vibration amplitude, means the current through the crystal.
An interesting picture gives us the comparison of the fundamental and overtone modes of the same crystal (figure 2). The vibrating volume is different (fig 3 and 4). Therefore the influence of the blank edges, the electrode edges, the glue and the holder is greater for the fundamental mode. The aging behaviour will be different for the different vibration modes. A similar effect is happen if high vibration amplitudes are used [2].

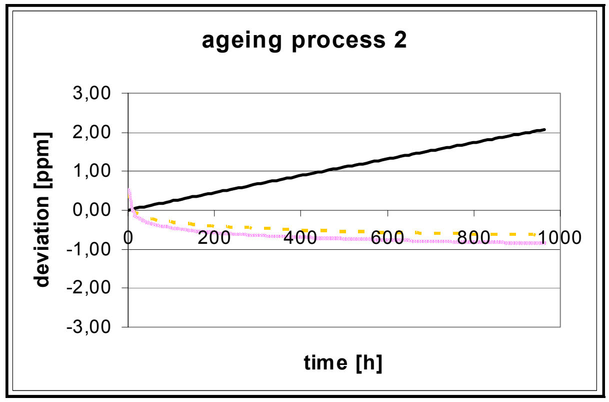

Figure 2 Different aging curves for fundamental (black) and overtone modes, in this case caused by electrode design

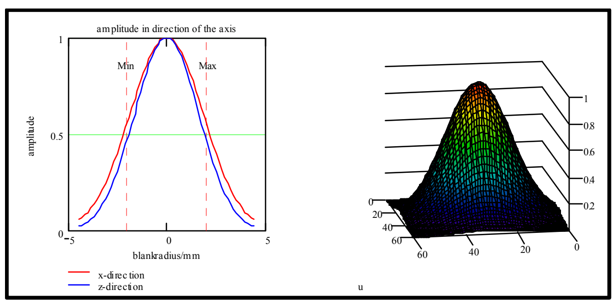

Figure 3 Fundamental mode vibration

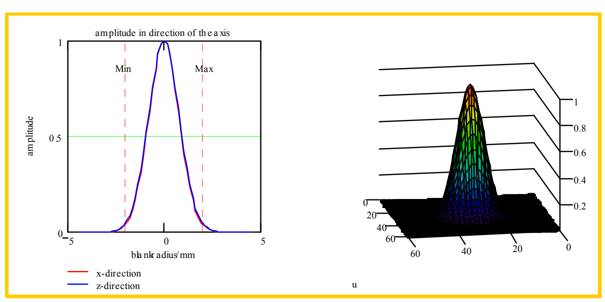

Figure 4 Overtone mode vibration

V. TEPERATURE DEPENDENCY

From the theoretical approach the temperature dependency should only influence the time constants of the different effects. The mathematical behaviour of the temperature dependency can follow the Arrhenius law for chemical reactions or the law for physical effects depend on the reason of the different effect. The function is for all of them an exponential function like $e^{\frac{E}{KT}}$ with different sizes of activation energies E.

VI. MICRO JUMPS AND RETRACE

The aging behaviour can be monotone or in abrupt steps (micro jumps). Monotone means, the changes are too small, to see the steps really. All physical processes have an energetically step size, like activation energy etc. But partly the energy is stored over time for a bigger step, like a healing process in the crystal lattice. A region of the lattice can change at once, if the stored energy in the lattice is high enough. Such effects could be the reason for micro jumps. Lattice defects exist in each material and the energy can be brought in by temperature or vibration amplitude.

A retrace effect is a physical stress effect with very short time constant which appears in the moment, the vibration starts or changes amplitude. Mostly influenced is this effect from the stress between electrode material and crystal surface and from the stress induced in the lattice by the vibration.

VII. RESUMEN

Normally only one or two logarithmic functions are used to describe the aging behaviour. But there exist also effects with non logarithmic behaviour over time. This is usable for medium decay times of around 50 days. For very long time aging one parabolic, one exponential and perhaps one logarithmic part determine the behaviour. The logarithmic part exist only for selected designs. Together with the amplitude factors and the decay time for the different processes a selective cost optimized production way is determine. If the crystal decay times are know, it is easy to find the oscillator influences and adjust them.

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