N93-29685

RADIATION SENSITIVITY OF QUARTZ CRYSTAL OSCILLATORS EXPERIMENT FOR THE LONG DURATION EXPOSURE FACILITY (LDEF)--PART II

J.S. Ahearn and J.D. Venables*
Martin Marietta Laboratories
1450 S. Rolling Rd.
Baltimore, MD 21227
Phone: 410/247-0700, Fax: 410/247-4939

ABSTRACT

The stability of high precision quartz crystal oscillators exposed to the radiation environment of NASA's Long Duration Exposure Facility (LDEF) has been studied. Comparisons between pre-flight and post-flight frequency drift rates indicate that oscillators made from swept premium Q quartz exhibited a significantly greater post-flight drift rate than before exposure, but that the effect annealed after five months aging at 75°C (the operating temperature). The result that six years worth of radiation damage annealed out in less than six months suggests that if the oscillators had been powered during the LDEF mission, no net change in drift rate beyond their normal baseline value would have occurred.

INTRODUCTION

In a prior paper,[1] we compared the stability in an LDEF environment of quartz crystal oscillators made from (1) synthetic swept premium Q quartz and (2) Brazilian natural quartz. These two particular grades of quartz were chosen because they exhibited large differences in radiation sensitivity when examined in the transmission electron microscope (TEM). Specifically, it was observed that under the influence of the electron beam (even for incident electron energies as low as 20 keV) defect clusters formed in both materials with the premium Q quartz exhibiting a more rapid development of the clusters and a larger cluster size (albeit at a lower volume density) for a given electron dose. We speculate that the clusters most probably formed from displaced atoms which condense at impurity sites, and that the clusters induce large strains in the lattice as evidenced by their black-dot contrast. The LDEF experiment, then, was an attempt to determine if there is a correlation between the damage produced in the electron microscope for different grades of quartz and oscillator drift rates which would be expected to be influenced by strain fields in the lattice.

PRIOR RESULTS

In Part I of this paper we reported on pre- and post-flight frequency drift rates for a total of 16 resonators, all of which were 5MHz fifth overtone AT-cut made for us by Bliley Electric. Eight of these were fabricated from synthetic swept premium Q material obtained from Sawyer Research Co. and the others from Brazilian natural quartz. Four resonators (two from each grade of quartz) were used as controls in the LDEF tray by shielding them from radiation with tantalum covers. Ten other resonators (five from each grade) were exposed to the space radiation environment and the two remaining (one from each grade) were kept in the laboratory as additional controls. For all oscillators, the drift rates were measured over two periods of approximately five months each prior

* Retired

to the LDEF flight to establish a "natural" drift rate, and then for five months after retrieval (post-flight) to determine the effect of the LDEF environment.

The results of our pre-flight and first post-flight aging studies (which were all done at 75°C) are summarized in the first two columns of Table I. It is evident that the radiation (estimated to total about 1×10^3 rads) has had little effect on the drift rates of the natural quartz resonators which, within experimental error, are the same before and after the flight. The swept premium Q resonators, however, exhibited a significantly greater drift rate in the post-flight studies that is positive in sign, i.e., the frequency increased with aging time. Since it is generally observed that radiation induced drift rates are negative when measurements are made during exposure (except at extremely high dose rates),[2] our result suggests an annealing effect in which the damage created during the LDEF flight is being healed during the 75°C aging studies. To test this hypothesis and an alternate possibility that the drift rate had been permanently altered in the swept premium Q resonators by the LDEF environment, we have performed a second series of post-flight aging studies.

SECOND POST-FLIGHT FREQUENCY DRIFT MEASUREMENTS

A second post-flight aging study was done in the same manner as the first by Bliley Electric with the resonators held at 75°C throughout the test. The data, which are summarized in the third column of Table I, indicate that the drift rates of the natural quartz resonators were again the same (within experimental error) as they were in the pre-flight and the first post-flight studies; no effect of the radiation environment was observed. The swept premium Q resonators that had been exposed to the LDEF radiation, and which had exhibited a relatively large positive post-flight drift, now show second post-flight drift rates approximately the same as the pre-flight value. This effect is further highlighted in Fig. 1 which compares the aging characteristics of a typical irradiated swept premium Q resonator during the first post-flight aging study (labelled 1990) and during the second one (labelled 1992). Evidently, the drift rate, which was initially high during the first post-flight study, has reverted back to its pre-flight value. We interpret this behavior as being due to an accumulation of radiation damage during the passive LDEF mission that anneals out during the 75°C aging tests, effectively recovering to the original condition (labelled 1982 in Fig. 1) during the first post-flight five-month aging period. By contrast, other premium Q resonators that had been shielded from radiation exhibited essentially no difference between pre-flight, first post-flight and second post-flight drift rates as shown in Fig. 2.

DISCUSSION

The data presented in Part I and Part II of this paper suggest some very important conclusions with regard to the stability of high precision quartz crystal oscillators in a space radiation environment as follows:

1. High precision quartz resonators made from swept premium Q quartz accumulated radiation damage during the LDEF mission that is evidenced by a marked increase in the initial post-flight frequency drift rates relative to the pre-flight values.

2. The effect slowly anneals out during the post-flight aging studies and after approximately six months in the aging environment (75°C) the drift rates return to their pre-flight values within experimental error. We attribute this annealing effect to the higher temperature seen in the aging studies than during flight when the mean tray temperature was estimated to be no higher than 30°C.

3. No effects of the LDEF mission environment were observed for resonators made from natural quartz.

4. The observation that nearly six years worth of radiation damage anneals out in less than six months at the normal operating temperature of quartz crystal resonators suggests that if the resonators had been powered during the LDEF mission, no net change in drift rate beyond their normal baseline value would have occurred. This observation has important implications for the use of quartz oscillators made from swept premium Q material, which has distinct advantages over natural quartz in some applications. For example, resonators made from swept premium Q material have been shown to be much more resistant to the effects of very high intensity, pulsed radiation than those made from natural quartz.[3]

5. Finally, it is worth noting that the LDEF mission has provided a unique opportunity to study the behavior in a true space environment of an important component of space communications and navigation, namely the high precision quartz crystal oscillator. It is true that many ground-based studies have been made in the past of radiation effects in quartz resonators, but to our knowledge never before have such studies been done at the extremely low dose rates characteristic of the levels incurred in this flight. For example, the lowest dose rate reported in the literature that we are aware of for ground-based studies was 1.4×10^{-2} rads(Si)/min. used recently by Norton.[4] By way of comparison, the rate of exposure seen in the present study on LDEF was approximately 3×10^{-4} rads(Si)/min. The significance of this is that even these very low dose rates can effect the drift rates of high precision oscillators. The good news, however, is that the effect apparently can be annealed out as fast as it is generated if the units are continuously powered.

REFERENCES

1. Ahearn, J.S. and Venables, J.D.: Radiation Sensitivity of Quartz Crystal Oscillators Experiment for the Long Duration Exposure Facility (LDEF). Proc. of First LDEF Post-Retrieval Symposium, NASA CP-3134, Part 3, Jan. 1992, pp. 1523-1531.

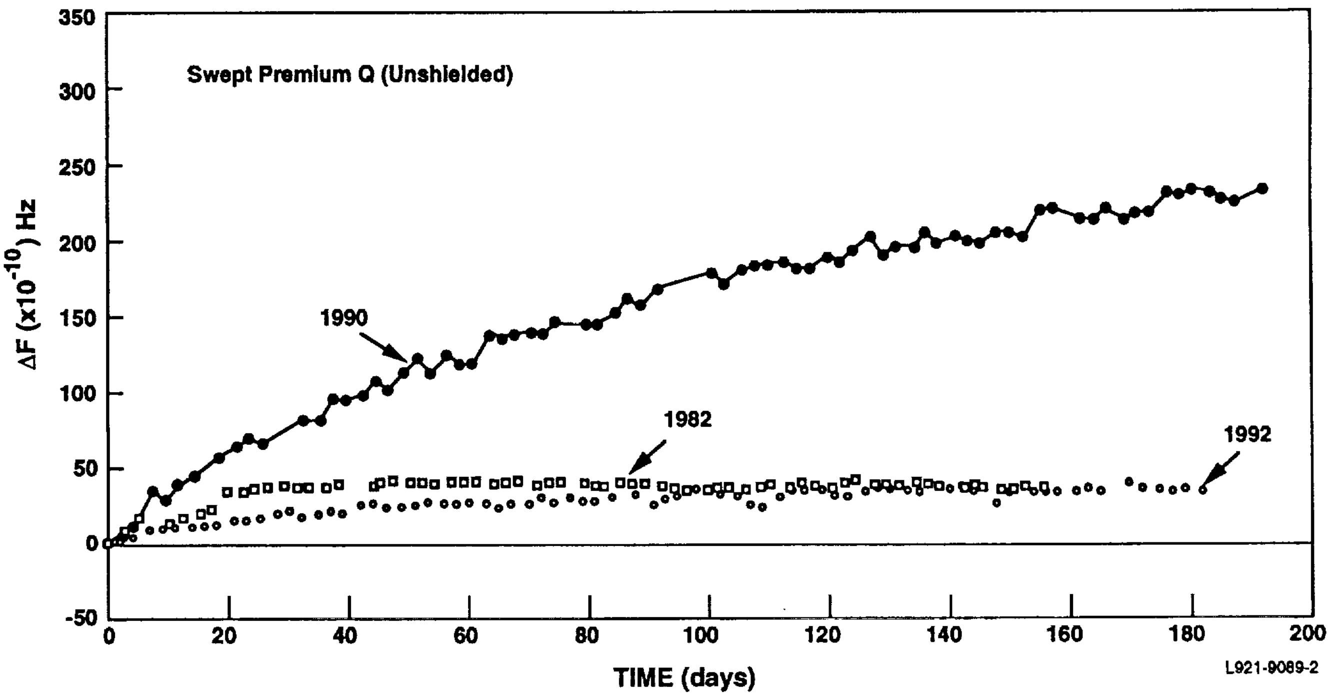
2. Suter, J.S.: IEEE Trans. Nuclear Scit. 37 (1990), pp. 524-528.

3. Euler, F., Lipson, H.G., and Ligor, P.A.: Proceedings of the 34th Frequency Control Symposium (1980), pp. 72-80.

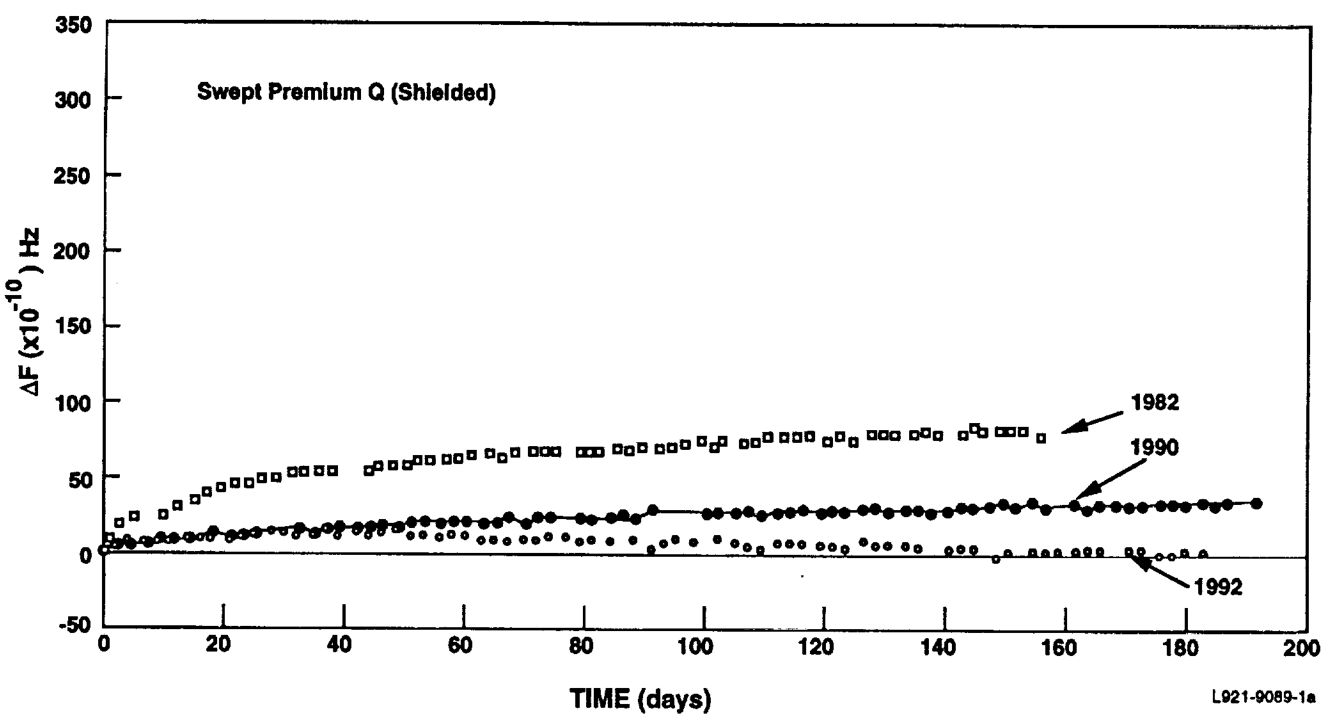
4. Norton, J.R.: BVA-Type Quartz Crystal Oscillators for Spacecraft. Proceedings of the 45th Annual Symposium on Frequency Control, Feb., 1991, pp.426-430.

Table I. Mean Drift in Resonant Frequency after 5 Months Aging (ΔF IN p X 10^{-10})

Type of Quartz	Pre-Flight	First Post-Flight Aging (irradiated only) 1990	Second Post-Flight Aging (irradiated only) 1992
Swept Premium Q	53 ± 53	217 ± 69	34 ± 24
Natural	40 ± 34	61 ± 47	60 ± 33



1. Aging results of unshielded resonator showing the change in resonant frequency as a function of time for Bliley Type BG61AH-5S resonators fabricated from Saywer Swept Premium Q material. Aging temperature 75°C.



2. Aging results of shielded resonator showing the change in resonant frequency as a function of time for Bliley Type BG61AH-5S resonators fabricated from Saywer Swept Premium Q material. Aging temperature 75°C.