A Comparison of Two Independent Atomic Time Scales*

Although the use of atomic beam devices clearly permits the measurement of time intervals of up to several years with a precision which is 100 times better than that available from astronomical measurements, the problem of preserving epoch exists if it is wished to replace the traditional astronomical timekeeping methods by quantum electronic techniques.

Two main approaches to this problem exist. The first involves securing reliable nonintermittent operation of an atomic frequency standard with clock-driving quartz oscillators locked to the instrument for realizing the atomic transition. With this approach, more than one atomic standard is necessary in each laboratory, since the expected lifetime for reliable operation of a single instrument is far from infinite.

The second, less expensive method requires intermittent use of the atomic standards to calibrate free-running quartz oscillators which drive clocks. These calibrations are then used to convert indicated quartz time to atomic time. The accuracy of this method depends on, among other things, how often the calibrations are made. One must also consider possible systematic errors arising from the possibility that the oscillators exhibit cyclic frequency variations having a frequency conciding with the frequency with which the calibrations were made. This type of error could arise, for instance, if during the measuring process the loading on the oscillator changed and this in turn induced a change in the frequency at which the oscillator was operating. This type of error could happen also if frequency measurements were made at an interval which is some integral multiple of 24 hours. Ambient temperatures and supply voltages ordinarily have 24-hour periods. Therefore, if the voltage and temperature regulating circuits of the oscillator were not functioning adequately because of design or deterioration of the components, a systematic error might be expected. Such a mechanism is known to have affected the measurements reported below by about 1 part in 10^{11}. However, some quartz oscillators which were designed more recently than those used in obtaining data for this paper show smaller accumulated time errors due to diurnal frequency variations even though the frequency measurement schedule was maintained on a daily basis over a period of several months.

The National Bureau of Standards, Boulder, Colo., has assigned atomic times to WWV pulses on a daily basis for a period of over four years. These assignments are made using daily frequency measurements of WWV based on the United States Frequency Standard assuming an atomic second as equivalent to 9,192,631,770.000 . . . oscillations of a source resonant with the zero-field hyperfine level spacing of Cs^{133}. They have been compared to similar assignments made by the U. S. Naval Observatory, Washington, D. C., according to their A.1 scale.[1] The variations in the daily differences in times as assigned by the Naval Observatory and by NBS are plotted in Fig. 1.

One would expect that over a period of 4 years measuring techniques would improve, causing a plot such as Fig. 1 to have smaller variations; and systematic errors would be found and eliminated, causing an approach to a more nearly horizontal line as time progresses. The latter has not happened, as is shown in Fig. 1. Analysis of the data seems to indicate that, although the general agreement tends to be within one part in 10^{10}, a persistent slope of about

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[1] "Time Service Notice," the U. S. Naval Observatory, Washington, D. C., No. 6; January 1, 1959.

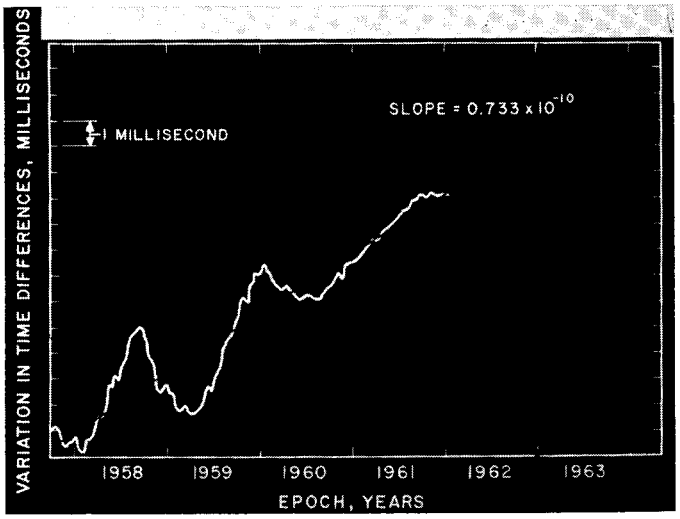

Fig. 1—Comparison via WWV of Naval Observatory A.1 atomic time scale and NBS atomic scale constructed from WWV frequency corrections. Positive slope implies Naval Observatory is slow or NBS is fast.

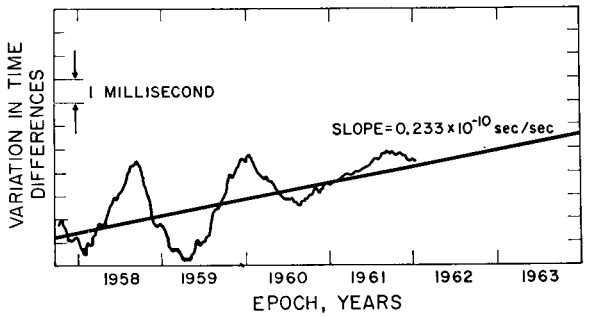

Fig. 2—Comparison of Naval Observatory and NBS atomic time scales after removal of 0.5×10^{-10} discrepancy.

0.7×10^{-10} sec/sec exists, upon which is superimposed irregular fluctuations whose significance, if any, is not known. These fluctuations are much smaller for the last part of the curve than for the first.

A large part of the slope is probably caused by lack of agreement among laboratories concerning the correction which is applied to the nominal frequency output of Atomichrons. This output was given as 9,192,631,840 cps before the common usage of 9,192,631,770 cps as the zero-field Cs frequency. Therefore, in order to obtain the operating output frequency of Atomichrons in terms of the presently accepted value of the Cs frequency a correction must be applied. The basic correction used in the construction of the A.1 scale[2,3] is 74.0×10^{-10}, while some laboratories, *e.g.*, Cruft,[2,4] use the value 74.5×10^{-10}. (NBS also used 74.5×10^{-10} prior to June 13, 1960, when the use of an Atomichron was discontinued and NBS II was adopted as the United States Frequency Standard.) This discrepancy accounts for most of the slope shown in Fig. 1. Fig. 2 shows a comparison of the two atomic time scales after the removal of the 0.5×10^{-10} sec/sec discrepancy, which leaves a slope of only about 2×10^{-11} sec/sec to be attributed to systematic errors.

Two clocks diverging at the rate of 2×10^{-11} sec/sec would require of the order of 100 years before their relative error would be as large as the error now present in the best measurements of astronomical time.[5]

The time pulses of WWV have been related to an atomic time base determined by the United States Frequency Standards in Boulder for the period of October 9, 1957, to the present, in addition to being related to the Atomic Time Scale A.1 of the Naval Observatory. The variations of these pulses from A.1 are regularly published by the Naval Observatory.[6] NBS intends to publish the variations of WWV pulses relative to the NBS Atomic Time Scale in the near future.

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[2] W. Markowitz and R. G. Hall, "Frequency Control of NBS on an International System (I)," U. S. Naval Observatory, Washington, D. C.; January 12, 1961.

[3] R. G. Hall, private communication.

[4] "Cruft Laboratory Frequency Comparison Reports," Cruft Lab., Harvard University, Cambridge, Mass., unpublished reports.

[5] W. Markowitz, R. Glenn Hall, L. Essen, and J. V. L. Parry, "Frequency of cesium in terms of ephemeris time," *Phys. Rev. Lett.*, vol. 1, pp. 105–108; August, 1958.

[6] "Bulletin B, U. S. Naval Observatory Time Signals," U. S. Naval Observatory, Washington, D. C. (published periodically by the Naval Observatory).