More on the Robertson Regulator

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1 Introduction

An article in HSN 2021-5 described the Robertson Regulator system as fitted to the Robertson Clock at Bristol University in the UK. It included some simulation results for the system attempting to synchronise to a daily time pulse as was distributed from the Greenwich Observatory by telegraph until the 1950s. These showed that the system essentially worked but it was not possible to reproduce results recorded on the actual clock by A. E. Ball in 1929. These showed that the system performed rather poorly when there were large and fast changes in barometric pressure.

One of the authors (AM) has observed anomalously large sensitivities to barometric pressure in one of his own clocks. He built a similar simulation and evaluated its behaviour with much larger sensitivity to barometric pressure that showed that strange behaviour could result. This is also now been observed in the original simulation and this article reports the results.

2 Results

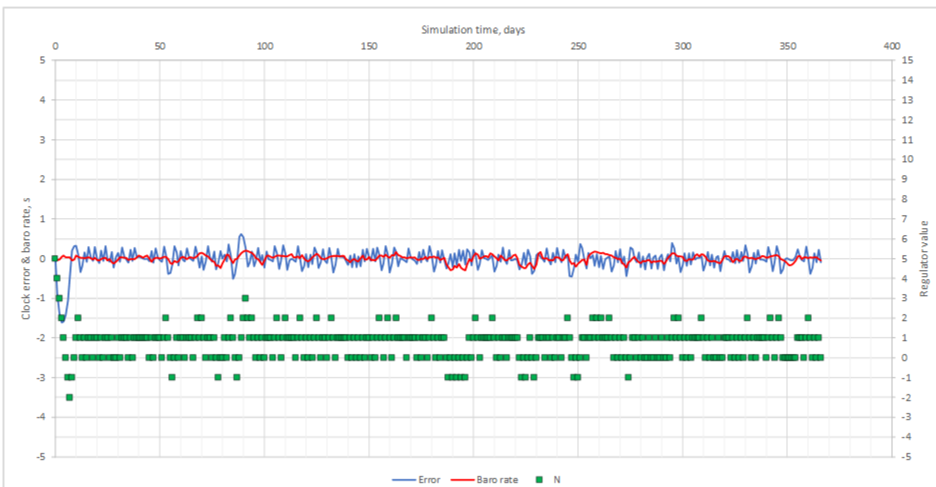

Figure 1 Expected behaviour with recorded pressure variations from NPL

Figure 1 (taken from [1]) shows the operation of the system using mean pressure data recorded at 15 minute intervals at NPL, London, from which are derived daily averages. These assume the expected variation in rate due to buoyancy and accession to inertia. It can be seen that the clock adapts its rate to the daily reference within a few days and thereafter remains within 0.5 seconds as the regulator adapts to barometric errors.

On the other hand Figure 2 shows the performance recorded by Ball during a period during which the barometer was changing very rapidly and over a large range. (We have had similar weather in the UK in February/March 2022.)

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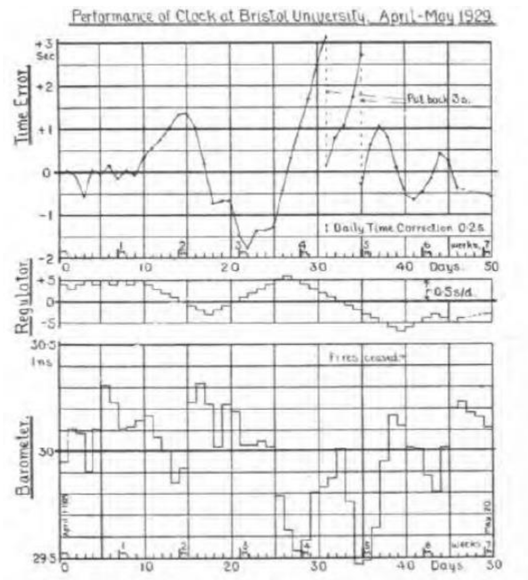

Figure 2 Ball's results

These show the rapid and extreme pressure changes and the resulting clock response – clearly the control system found it impossible to cope. Creating a file of pressure values from Ball's plot, and running the simulation did not show these effects. Given AM's observations we re-ran the simulation with variable barometric sensitivity and investigated how the behaviour changed.

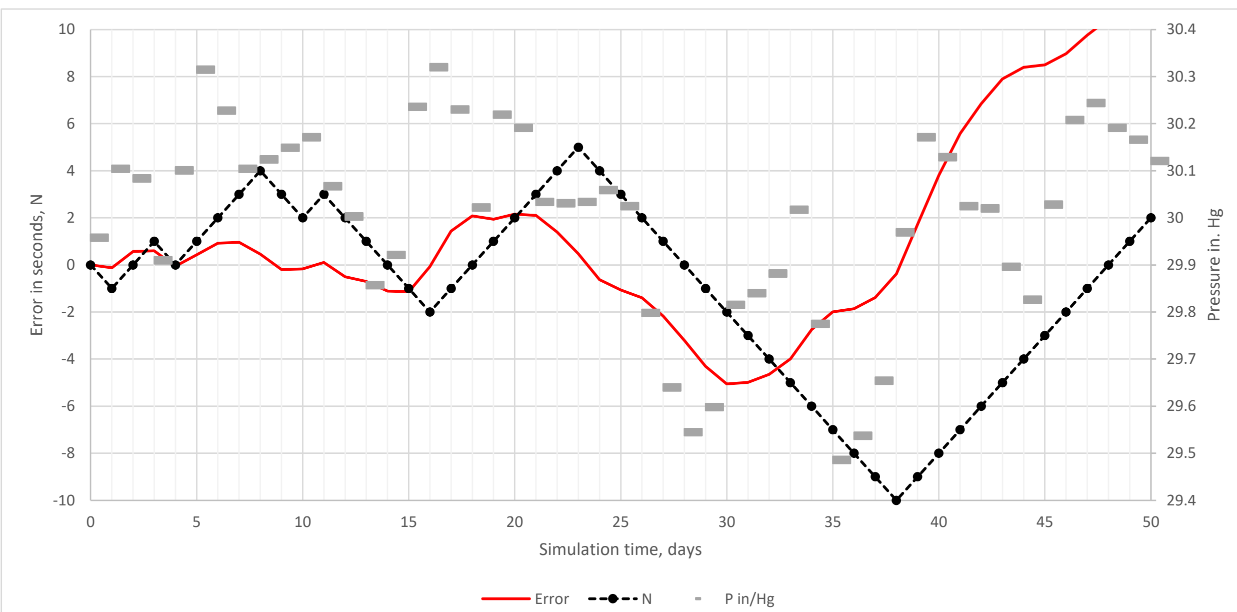

Figure 3 Simulation results with 9.5x sensitivity to pressure

Assuming that the barometric coefficient was 9.5 times larger than expected similar effects start to be observed as Figure 3 shows. Both the shape and the magnitude of the errors are similar to those that Ball observed. It remains to be seen whether this large increase could be explained by variation of escapement deviation with amplitude as the air drag changes.

Another view can be obtained using the year-long barometric data from NPL (Figure 1) and applying a multiplier to the barometric sensitivity. Figure 4 shows error plots for a year for 4 different barometric coefficient multipliers, all much less than the Figure 3 simulation.

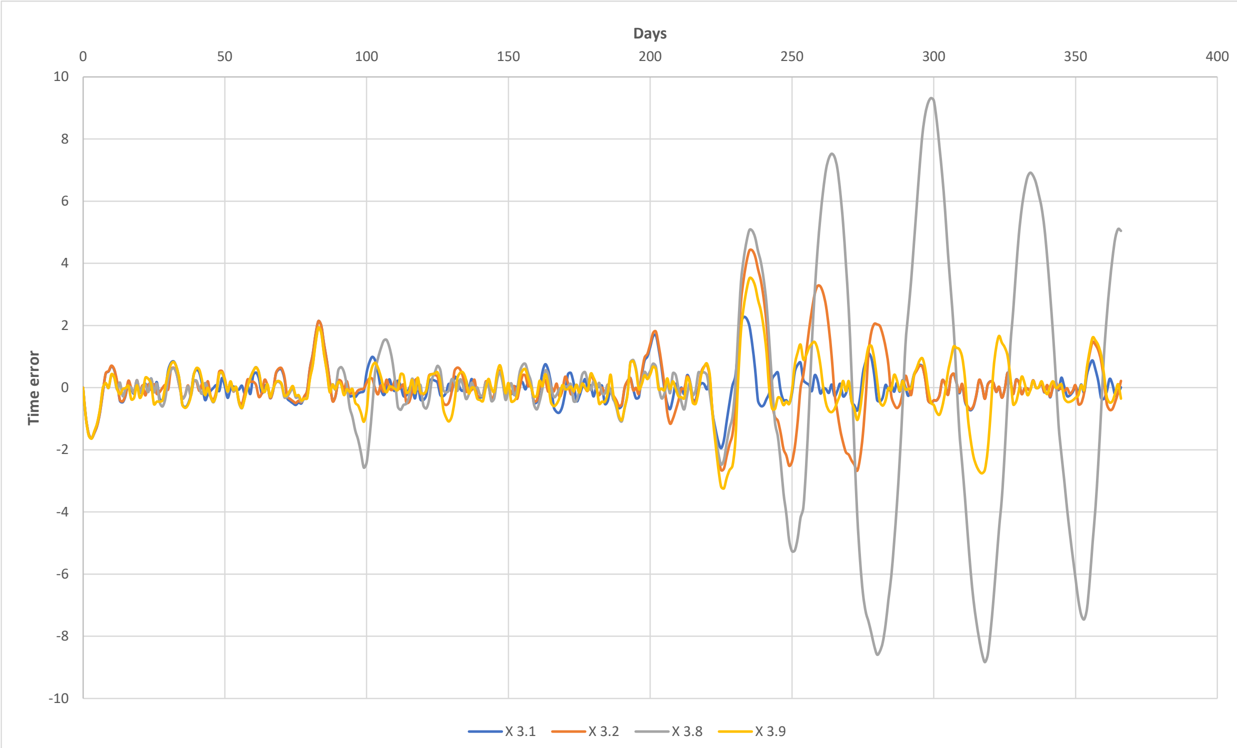

Figure 4 Simulations with annual pressure data and different sensitivities

A multiplier of 3.1 (blue curve) just starts to show significant extra variations around about day 240. A slight increase to 3.2 gives a larger variation; and 3.8 much larger still; but at 3.9 the variation is much smaller! (Actually if the multiplier is reduced to 2.9, there is again a large variation.) It would seem that the regulator system is highly non-linear and its dynamic behaviour is very dependent on the magnitude and slope of the pressure variation. The large variations in Figure 4 would be occurring around the autumn equinox when large pressure variations and high winds would be expected. The system is very sensitive to small changes in parameters.

3 Discussion

Simulations of the Robertson Regulator system using the barometric pressure profile observed by A E Ball in 1929 but assuming that the barometric coefficient of the pendulum is much larger than would be expected based on just buoyancy and accession to inertia show that much larger time error excursions can result. In particular if one assumes that the coefficient is increased by nearly 10 the time error corresponds reasonably well with Ball's observations in both shape and magnitude. Even with much lower coefficients similar behaviour can be observed using the long-term pressure data.

We have hypothesised that this much larger barometric effect is caused by variations in the pendulum's amplitude caused by changing air drag that affect its rate through excessive escapement deviation, considering the lagging impulse inherent in Robertson's design. The pendulum's design is unusual in having two quite substantial "rods" in the form of flat invar strips; and also in having the paraphernalia of the rate-adjusting linkage in between them. All this probably makes the pendulum drag quite large and therefore its amplitude more sensitive to pressure variations. So far the pendulum Q has not been measured – it is hoped that some instrumentation can be added to the clock to allow measurement of its amplitude so that run-down Q tests can be done and also its sensitivity to pressure.

Essentially, the Robertson Regulator is limited by its low sampling rate relative to the timescale of air pressure variations, and its inability to “slew” its rate fast enough. As a result it becomes essentially unstable when the rate of pressure variation is too large.