

DETERMINATION OF RESPONSE RATES OF WOODEN OBJECTS TO FLUCTUATING RELATIVE HUMIDITY IN HISTORIC PROPERTIES

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ABSTRACT

The response of a piece of historic furniture exposed to natural fluctuations in the ambient temperature and relative humidity (RH) has been determined, using a minimally intrusive displacement sensor. Changes in the width of a previously existing crack were monitored and were found to follow changes in relative humidity closely. The cross-correlation function of the crack width and the RH was calculated, and showed that the crack width followed the RH with a time lag of approximately 41 hours. The object hardly responded at all to more rapid fluctuations.

INTRODUCTION

Although there have been many laboratory studies on dimensional changes in wood caused by changes in RH, there have been very few studies of the effects of seasonal changes on historic wooden furniture in its normal display environment. This is an important distinction, because laboratory studies typically measure the rate at which a sample reaches equilibrium after a step change in RH, whereas in the natural environment RH changes are cyclical and artefacts rarely reach equilibrium.

The effects of changes in RH on wood are well documented in the literature [1]. There is anecdotal evidence in the conservation literature of catastrophic effects of RH extremes on historic wooden furniture, but it is not known whether there is a threshold in the magnitude or rate of RH change below which damage will not occur, or whether the cumulative effect of many small changes can cause catastrophic failure. There is evidence that the environmental history of a piece of furniture can substantially affect its behaviour.

Erring on the side of caution, conservators have specified a very tight range of acceptable RH, typically $55\% \pm 5\%$, but as Thomson pointed out many years ago, this was 'based more on what can be expected of an air-conditioning plant than on what exhibits can actually stand without deterioration, which is not known in any detail' [2]. Suggestions that this standard might be relaxed [3] were treated

almost as heresy, but little evidence has appeared to support either side of the argument.

An opportunity arose to investigate how a piece of historic furniture would react to its display environment, when English Heritage purchased two tables, originally made for Chiswick House in West London [4]. The tables consist of elaborately carved and gilded wooden frames, supporting heavy inlaid marble tops. Visual examination and radiography showed that the decorative elements were made of several blocks of wood glued and nailed together before being carved. Differential movement of these blocks had led to cracks in the gesso overlaying the joints. Before the tables underwent a lengthy and expensive period of conservation, the question was asked whether the tables would be harmed by being displayed in their original location in the Gallery at Chiswick House, which has a ducted warm air heating system capable of humidifying but not dehumidifying the air. It achieves reasonable control over the temperature, but less effective control of RH, which rises above 70%, and drops below 30% in the winter months. The tables were temporarily displayed in the Gallery between November 1997 and January 1998, and it was decided to attach a displacement sensor across a crack in the back of one of the decorative swags on one of the tables, in order to monitor changes in the width of the crack. The measurement used existing holes in the wood and minimised damage to the table.

METHOD

The sensor used was a linear variable differential transformer (LVDT), which converts very small displacements into a voltage signal. The LVDT is



Figure 1. Transducer attached to rear of table

about the size and shape of a ball-point pen. The body of the sensor was held by an Ω -shaped bracket on one side of the crack, while the movable ball end bore against an L-shaped stop on the other side of the crack (Fig. 1). This arrangement allowed opening and closing of the crack, and expansion and contraction of the wood to be measured.

The LVDT was connected to a signal conditioner which supplied it with an accurately controlled AC voltage, the output voltage was rectified and amplified to produce a DC signal that was proportional to the displacement of the sensor. This signal was recorded by an ACR SR-7 datalogger. The ambient temperature and RH were recorded by an ACR SR-2 datalogger. The measuring system was calibrated using automotive feeler gauges, in the range 2 – 10/1000 inch (50.8 – 254 μ m), and gave a good linear graph. The resolution of the system (limited by the resolution of the datalogger) was 1.77 μ m. Note that the absolute width of the crack was not measured (it was about 2mm), but changes in the width.

RESULTS AND DISCUSSION

Data were collected at 30-minute intervals for the period 6 November 1997 to 29 January 1998. During this time the temperature varied between 11.3°C and 20.2°C (though it was generally between 16°C and 18°C), while the RH varied between 32% and 74%. The maximum change in the width of the crack was 96 μ m – about 0.1mm.

Looking at the data (Fig. 2), it is obvious that the changes in the crack width (ΔW) follow the changes in RH, but are slightly delayed. The effects of temperature changes are insignificant. It can also be seen that while the table responds to RH changes with a period of ten days or more, it responds hardly at all to the diurnal RH fluctuations. In effect, the table acts as a low-pass filter, removing the faster changes and responding only to the slower ones.

The length of the delay between the changes in RH and the corresponding changes in crack width can be investigated by the mathematical technique of correlation, which measures how the similarity between two periodic functions changes as the time lag between the two is changed [5]. In effect, one dataset is slid past the other until the position of best match is found. A program was written to calculate the cross-correlation function of the two datasets as the lag was increased from 0 to 5 days. This showed that the maximum correlation occurred at a lag of 41 hours (Fig. 3). The maximum is quite broad, because

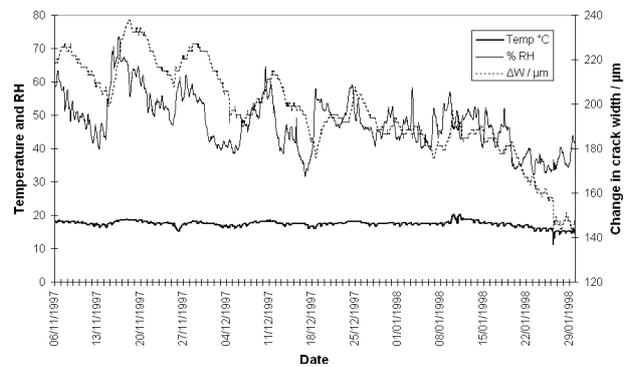


Figure 2. Crack width, relative humidity and temperature

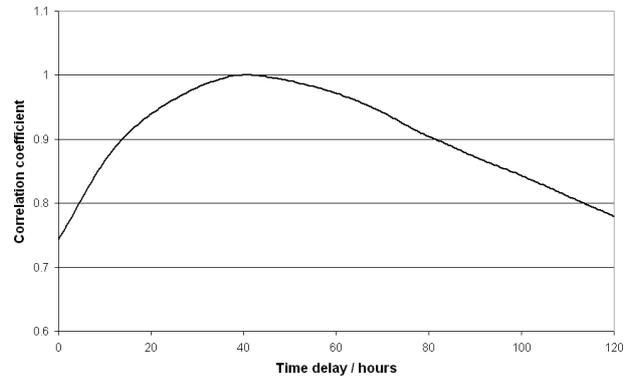


Figure 3. Cross-correlation coefficient of crack width and relative humidity

different parts of the table respond at different rates, according to their thickness, surface geometry and orientation with respect to the axis of the tree.

The implications of this are considerable. It means that any cyclic change in RH that is completed within about 41 hours is hardly felt by the table: while the surface layers do respond, the deeper layers do not respond at all to rapid changes. Only changes taking place on a longer time scale affect the deeper layers, but it is probable that the table does not reach equilibrium, even with these slower changes. The delay in the response is due to the slowness of the diffusion of water vapour into the core of the object; the gilding will also act as a partial vapour barrier.

Fig. 4 shows the crack width superimposed on the RH trace, which has been filtered by taking a 24-hour running average and shifted by 41 hours. It can be seen that there is now a very close match between the two patterns. Another example of the lack of response to rapid changes is shown in Fig. 5. On 3 January there was a rapid increase in RH, starting from 46% at midnight, reaching a maximum of 58% at 0900 and returning to 46% at 1600. The maximum response of the table would therefore be expected to have occurred 41 hours after 0900, or at approximately 0200 on 5 January. In fact, the crack width decreased steadily with no sign of an increase at this time.

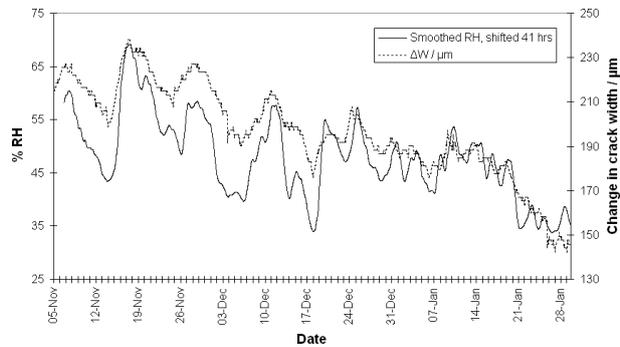


Figure 4. Crack width and smoothed, delayed relative humidity

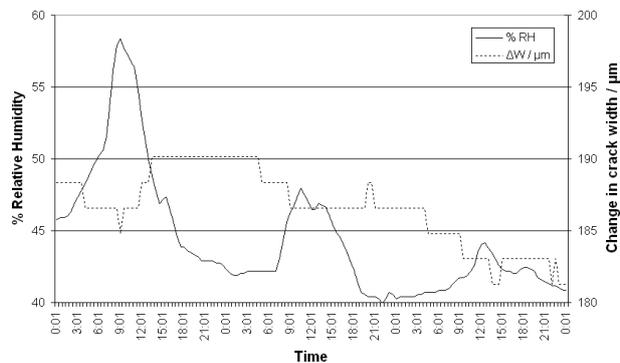


Figure 5. The crack width does not respond to rapid changes

Throughout this monitoring period, the trend of RH was downward, reflecting the normal seasonal changes, and the trend of the crack width was likewise downward. However, there is some evidence that the table releases accumulated stress by sudden jumps – a slip-and-stick mechanism. On 4 December there was a sudden decrease in crack width of $14\mu\text{m}$, followed by a small recovery, not associated with any change in RH. Similarly on 26 January there was a sudden decrease of $12\mu\text{m}$, associated with a small rise in RH and a fall in temperature – this may have been caused by opening the external doors. Changes of this size would normally be expected to result from RH changes of at least 10%, so this suggests that large changes in crack width can sometimes be caused by small perturbations.

Since this work was completed, other studies of the response of wooden artefacts to environmental changes have been undertaken, notably in connection with the “Friendly Heating” project [6]. Bratasz and Kozłowski [7, 8] describe a sensitive, non-intrusive optical system to record dimensional changes in polychrome wooden statues in a church, and relate the rates of change to stresses developed in the objects. Interestingly, they did not observe any lag between the fall in RH caused by the sudden increases in temperature when the hot air heating system was switched on, and the corresponding dimensional changes. This is probably because the optical reflector is adhered to the surface of the

object, and therefore records the rapid response of the surface, whereas in the experiment described here, the sensor is screwed to the object and therefore records the response of the object as far as the depth of the screws, about 10mm. The dimensional changes recorded are therefore smaller and more delayed. This effect was demonstrated in computer simulations by Padfield [9], in the context of the buffering of RH by wood.

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SUPPLIERS

Linear displacement transducer model GTX1000, transducer indicator type E309: RDP Electronics Ltd, Grove Street, Heath Town, Wolverhampton WV10 0PY, UK

ACR dataloggers, types SR-2 and SR-7: Status Instruments, Green Lane, Tewkesbury, Glos GL20 8HE, UK

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