AN ARTIFICIAL HAND USED AS A MEASUREMENT DEVICE

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Abstract. *This paper will outline the development an artificial hand which has been used as a test rig for heated gloves in a controlled and accurate manor. The artificial hand can simulate blood flow velocity and pressure using Peristaltic Pumps and micro bore silicon tubing. The primary function of the hand will be to simulate a Raynaud's attack, whilst recording the effect of external stimulus on the artificial blood temperature, flow rate and pressure. Hand Arm vibration may also be quantified; as a result the strain and vibration effects must also be measured.*
In order to obtain accurate stress and temperature responses a material with similar thermal conductivity and structural density to human flesh was developed and this material was then moulded around the finger.

Keywords*: Artificial, Hand, Raynaud's phenomenon, Hand Arm Vibration Syndrome*

1. INTRODUCTION

Raynaud's phenomenon is a disorder which affects the blood vessels in the body's extremities. The disorder is characterised by episodic vasospastic attacks usually in response to a change in temperature that causes the blood vessels in the digits and elsewhere to contract. Raynaud's phenomenon can occur on its own, or it can be secondary to another condition such as systemic sclerosis or systemic lupus erythemotosus. Raynaud's phenomenon can cause a drastic reduction of the blood supply to a particular body part which may result in numbness, intense pain and tissue damage. In the most severe cases, ulceration and gangrene can occur. An example of how severe the temperature differences can become in a Raynaud's patients hand during an attack is shown in Fig.1, where the cold parts of the patients hand have become white due to the reduced blood flow.

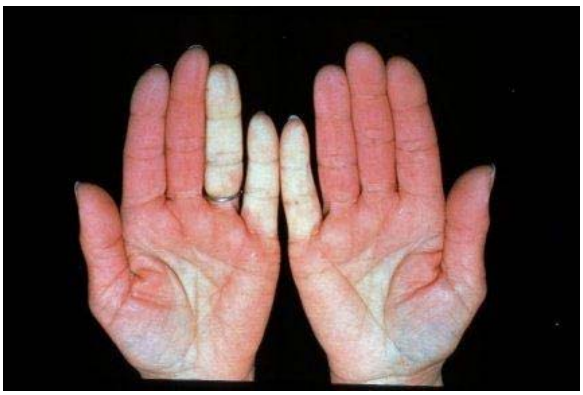


Figure1. Raynaud's phenomenon: reflex vasoconstriction.
From http://webrheum.bham.ac.uk

One approach to treating Raynaud's phenomenon has been the use of artificially heated gloves. Although it has been shown that such devices offer some therapeutic benefit, their use is often limited due to the bulky and heavy battery pack required. Another problem is the fact that the gloves are heated uniformly across the whole of the glove causing those unaffected parts of the hand to overheat.

In order to test the effectiveness of heated gloves currently available, a method of quantifying the benefits and efficiencies of them had to be created. This was done by constructing an artificial hand simulating the exact situation occurring in a patients hand during a Raynaud's attack, including the blood velocity and temperature gradients. The results of these tests would then be logged and evaluated to determine the effectiveness of each glove (www.lef.org, Block and Sequeira, 2001, Laundry et al., 1996, Lauchli et al., 2001).

2. DESIGN SPECIFICATION AND REQUIREMENTS

The design brief called for a 'hand' that could fulfil two distinct functions; 1) simulate a Raynaud's attack; 2) measure a gloves response to this simulated attack. To simulate blood flow the artificial hand will need to be able to produce a flow in the range of 0.5 - 2mm/s at atmospheric pressure and also the temperature must be controlled very accurately between 15ºC and 40ºC.

The human body is made up of 60% water; as a result the thermal conductivity of human tissue can be estimated to be around 0.6 W/mK. In order to develop an accurate model of heat transfer stress analysis on the artificial hand, a skin substitute will be required with a thermal conductivity and structural density similar to that of human tissue.

2.1. Design Details

At the core of the design is a metal skeleton made of thin wall copper tubing which houses the inlet and outlet channels for the artificial blood vessels and the wiring loom for the sensors. Figure 2 shows the skeleton in detail clearly showing the artificial blood vessel openings.

The artificial blood vessels are made from flexible micro-bore Portex Translucent PVC tubing (altecweb.com). This particular tubing was chosen for its cost effectiveness and ease of incorporation into the design, while also meeting all the specifications for the artificial blood pressure and velocity. When considering this tubing it was important that the pipes not kink on the tight radii of the finger, as the PVC tubing has a minimum bending radius of 7.5mm it is within the tolerances of the design. Figure 3 shows the internal network of the artificial blood vessels wrapped around the skeleton. The inlet and outlet of the three sections are clearly shown going through the skeletons internal cavity.

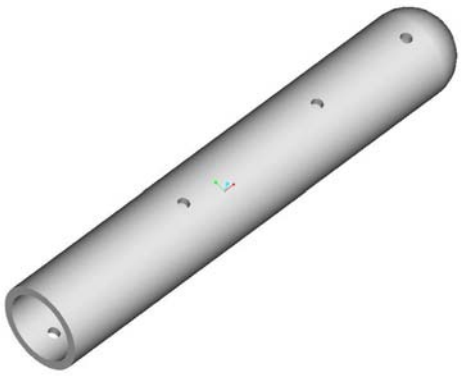


Figure 2. Skeleton of the finger.

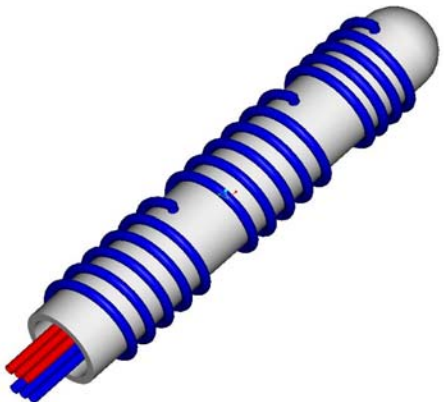


Figure 3. Internal network of the artificial blood vessels

All the pipes are connected by Luer quick connectors, these connectors allow for a smooth and clean transition between the micro bore tubing and the other major components. A vital part of the design is to accurately heat the substitute to a given temperature and be able to maintain it at a constant temperature, thus minimising the effect of ambient temperature. To achieve this, a modified Mini Bottled Water Cooler is used to cool the 'blood' before being pumped round the system. The modifications enabled precise control of the coolers outlet speed and incorporated an open inlet tank. This allowed for a continuous flow to pass through the cooler, completing the feedback of the system.

Each heater tank incorporates a heater element placed in the center of the tank and to ensure even heating an agitator is used, the completed tank and agitator is shown in Fig. 4. The heater elements comprise three 10mm cartridge heaters and they are capable of heating the artificial blood to 40ºC in 15 minutes.

Peristaltic pumps are used to drive the 'blood' through the system. These pumps were used because of their ability to pump at very low velocities, whilst not contaminating the flow or inducing residual heat. Another important reason was their ability to generate a heartbeat like flow. The pumps were designed and built within the department. Figure 5 shows one of the peristaltic pumps.

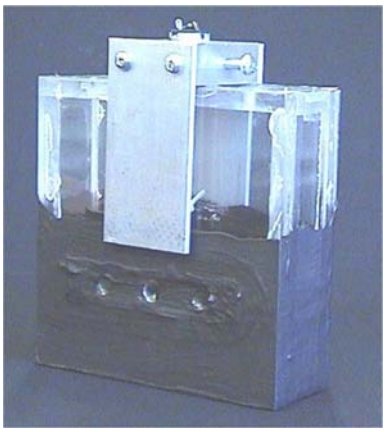


Figure 4: Heater tank and Agitator.

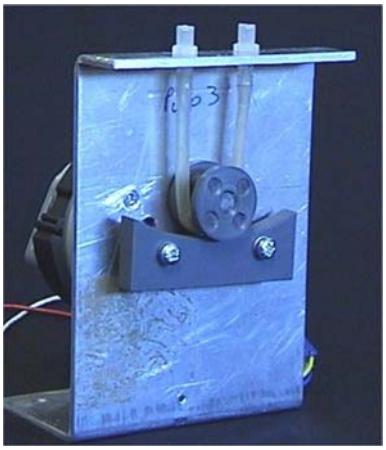
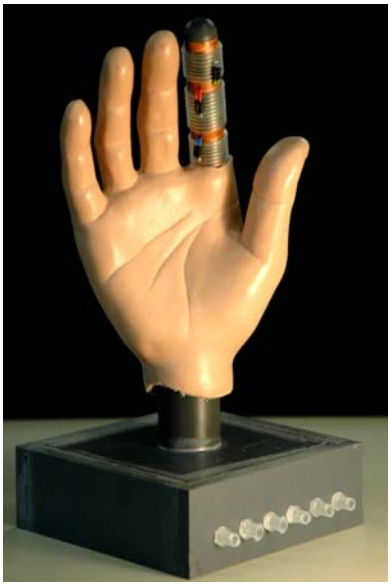


Figure 5: Peristaltic pump.

The hand itself is fitted on to a pedestal, this allows for easy manipulation of any external stimuli and enables a smooth transaction for all the cabling and tubing. Figure 6 shows the system in its entirety as well as a close up of the prototype hand and sensory digit.



A B

Figure 6: (A) Complete system, (B) hand with sensory digit.

2.2. Sensor Specifications and implementations

Sensory requirements for the hand range from surface temperatures, vibration and vertical and horizontal strains on the finger. Surface temperature is taken by using a Flat Film Pt100 Elements, as the sensor is to be placed between the blood vessels and skin for an accurate reading; it was custom made to accommodate the limitations on space. The sensor has a temperature range of -100ºC to 500ºC with an accuracy of ±0.5ºC; this is well with in temperature specifications for the system. The sensors had to be moulded to the curvature of the artificial fingers, however this stretched the sensor changing the resistive values, meaning it must be recalibrated.

A FLIR SC3000 thermal imaging camera was used to recalibrate the sensors which are connected to Wheatstone bridge arrangements. Thermal imaging can only be used to calibrate the sensors, as it can only measure temperatures it can see i.e. when a test glove is placed over the hand it can only measure the external temperature of the glove not the temperature of the finger inside the glove.

Vibration is measured by a Bruel & Kjaer accelerometer type 4333. These were chosen for their low error at low g-forces and for its small size. Finally strain gauges are used to measure the strain; these are imbedded in to the skin to represent a fully accurate model of the strain. Two strain gauges are used one placed horizontally the other vertically, again this adds to the overall accuracy of the system.

3. ARTIFICIAL SKIN

As previously mentioned the thermal conductivity of human tissue is 0.6 W/mK, to accurately model human tissue a substance which has a similar structure and thermal conductivity had to be used. The substance used was a water based Hydrogel with a minimum of 60% by weight water to give a thermal conductivity of around 0.6 W/mK and an accurate representation of human tissue. Poly Vinyl Alcohol (PVA) Hydrogel with chemical crosslink's was used; this met all the specifications needed.

The gel itself followed a standard crosslinking process of PVA crosslinked with glutaraldehyde. This process was chosen over the simpler hydrogen bonding system as it gave much greater mechanical integrity and longevity, Briefly, 2.5g PVA (90% hydrolised) was added to 25ml water at 80^{O}C and stirred until fully dissolved. After being allowed to cool, 7.5ml glutaraldehyde (50% aqueous solution) was added dropwise into the PVA under agitation. To catalyse the crosslinking reaction, 5ml of 0.1M H_2SO_4 was then also added dropwise. The solution was stirred for several minutes to ensure homogeneity and then it was poured into a split mould. Full gelation occurred within a few hours to produce soft, elastic, but mechanically strong skin over the skeleton.

Due to the Hydrogel acting as artificial skin, a method of coating the metal skeleton had to be developed. This is done by using a split mould with two injection holes, to control the Hydrogel during the casting process. The skeleton including all sensors and blood vessels is then inserted and sealed into the mould; Hydrogel is then pumped in to the mould using syringes. Once the gel has set, the mould can be split open revealing the skeleton with all the components in place and coated with the artificial skin.

4. TESTING AND SENSOR CALIBRATION

Testing the sensors is undertaken by first setting the artificial blood temperature to 37ºC. The thermal imaging camera is then be used to validate the temperature and recording any thermal losses in the system. If a loss is detected in the system, the heaters can be adjusted to compensate for it. The sensors can be then zeroed (using the Wheatstone Bridge) at 37ºC, normal body temperature. With the sensors zeroed at 37ºC any increase or decrease in temperature is detected by a positive or negative voltage shift. Inputting this voltage into the A-D converter on the controller allows for an accurate surface temperature to be recorded. A schematic of the system is shown in Fig. 7

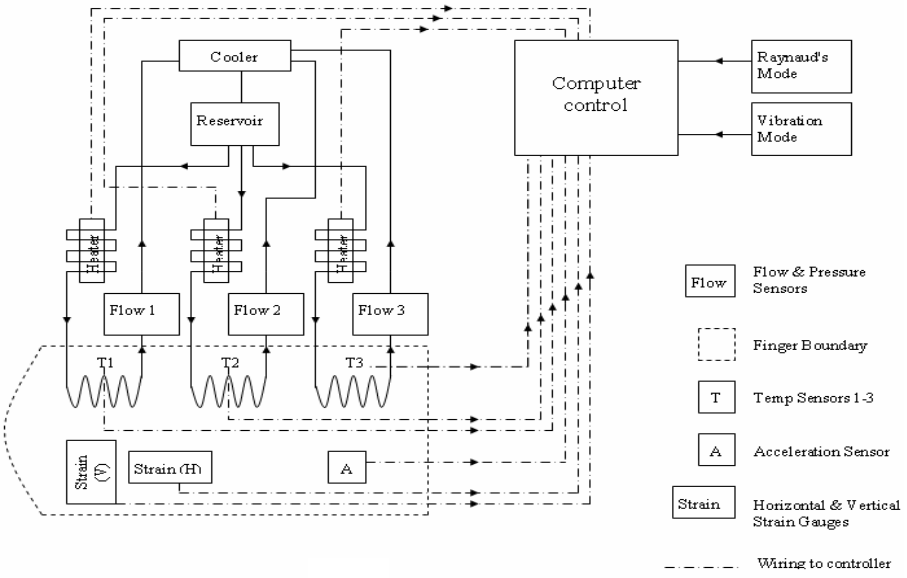


Figure 7: Schematic of the Artificial hand.

4.1 Thermal Test 1

Test 1 was to ensure an even heat distribution as well as measuring heat loss and calibration time, the test parameters were as follows:

Heater tank 1 = 4ºC

Heater tank 2 = 80ºC

Heater tank 3 = 4ºC (this set up will give two cold regions at the top and bottom of the finger while having a hot region in the middle)

Pumps 1, 2 are running at 2mm/s

Pump 3 is running at 0.2mm/s

Ambient temperature is at 22ºC

Run time 15minutes

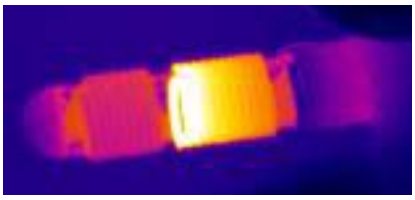


Figure 8: A thermal image of the finger during the test.

The colour in the image represent the temperatures in this case the lighter colour indicates a temperature of 35.4ºC and the darkest colour is 20ºC. The image also demonstrates that the slower flow in section 3 is distinctly warmer then that of the section 1, highlighting the importance of velocity of flow to minimise heat loss. The image is showing an uneven heat distribution throughout the various sections, this could be due to an insufficient calibration time or due to absence of the artificial skin which will act as an insulator and dissipate the heat more evenly.

4.2 Thermal Test 2

For the second test all the variables will be kept constant but the experiment will run for 30 minutes and only the middle section will be operating.

This test shows vast improvements in the heat transfer through the middle section giving a valid calibration time of 30 minutes.

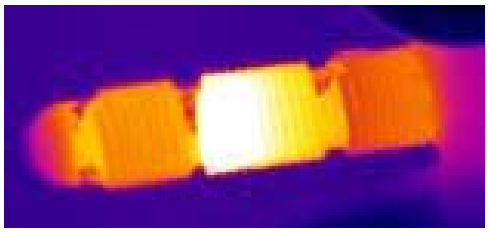


Figure 9: The finger 30 minutes into the experiment.

5. CONCLUSIONS DRAWN FROM THE TESTS

The results from these tests showed that there was a large thermal loss in the system and this lead to a redesign of the finger. The thermal loss was mainly caused by the use of the copper tube as the skeleton of the finger. This was replaced with by PVC tube and the micro-bore tubing used for the blood vessels was replaced by PTFE tape. Surface mount negative temperature coefficient RTD thermistors were encased in resin to protect them from the skin as it is mildly corrosive when wet and placed next to the PTFE tape. The RTD sensors have an accuracy of ±1°C over the range of 0°C to 100°C. As it was not essential to have an anatomically correct model, just thermally correct, the pumps were also changed from peristaltic to centrifugal. The final change was the skeleton of the finger is now fully integrated into the hand instead of just being pushed in as before.

These changes have given a more realistic response to the system with the average heat loss in the system between the pump and the finger now only 2°C. Figure 10 shows the uncoated new finger beside a hand for comparison purposes and Fig. 11 shows the second prototype finger with a skin attached. This was the first moulding of the ‘skin’ and problems were experienced with the curing of the hydrogel. Work is ongoing to improve the curing and lifetime of the coating and results will be shown at COBEM.

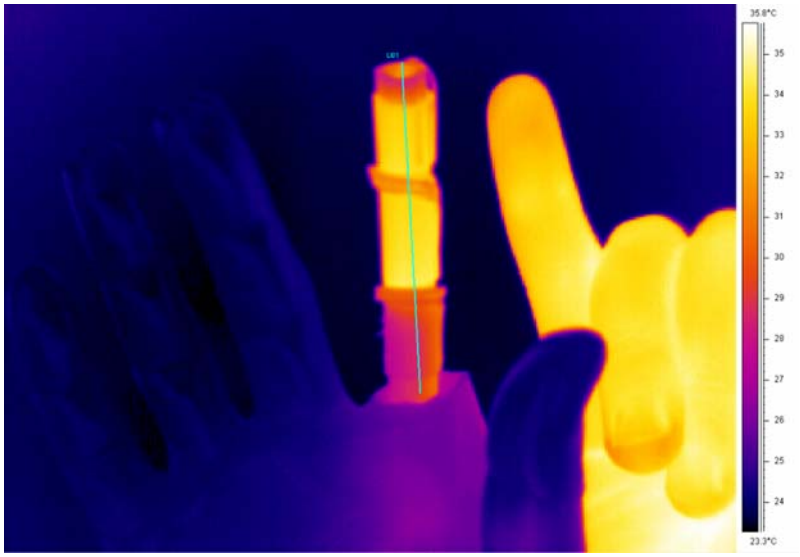


Figure 10: The second prototype finger response compared with a real hand.

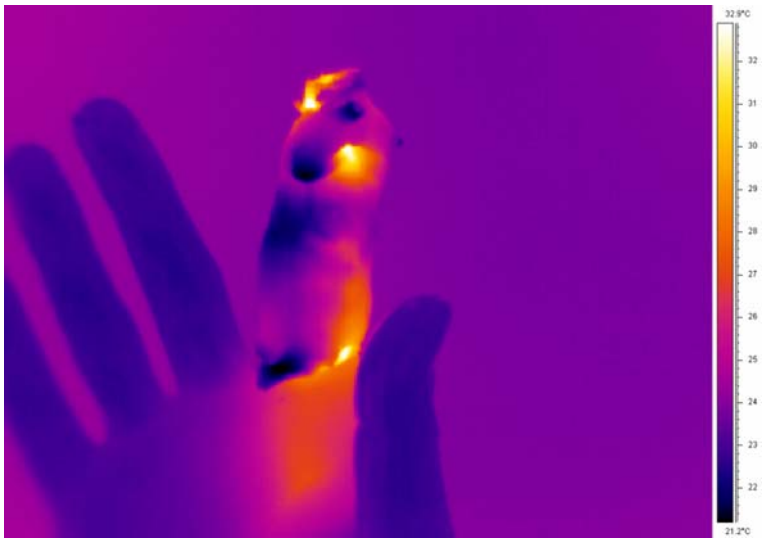


Figure 11: Tests of the first 'skin' on the second prototype.

6. CONCLUSIONS

The development of an artificial hand incorporating a simulated blood flow and sensory feedback has been described along with details of the initial tests to calibrate the system. These tests lead to a modification to achieve a much more realistic thermal response to the hand and results of first tests on the modified hand are shown. The first results using an artificial skin covering are also shown. All of these tests are ongoing as the research continues and results of the improved skin will be shown at COBEM. The hand will be initially used to test various heated gloves to test their performance, and then to develop smart gloves that can be used by suffers from Raynaud's phenomenon.

7. PATENT INFORMATION

The work described within this paper is protected by patent GB0605384.7.

8. ACKNOWLEDGEMENTS

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