WHITE PAPER

Accelerated Balloon Forming for Long Heating Blocks

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Abstract: A uniform temperature distribution inside the heating system is crucial to manufacture high quality PTA balloons. This is studied on single controlled, dual controlled and the optimized, rapid heating block system. The step respond to a high temperature was observed at five different points along the axis of the heating block. The single controlled heating block shows the most uniform temperature distribution during heat-up, however, the worst in steady state. The rapid heat block shows a reasonably good temperature distribution during heat-up and a superior temperature distribution with differences below three degrees Celsius in steady state. The system is currently optimized in regards of the heating power as well. Therefore, these results are preliminary.

Introduction

Developing and manufacturing extremely long PTA balloons is still a challenging task. To support the medical device manufacturers, BW-TEC has studied and improved the heating and cooling system for the heating blocks. For lengths equal or longer than 180 mm, an even temperature distribution along the balloon axis becomes very important and challenging to provide good quality balloons. A new heating concept was implemented and tested. The results are described here, where's the optimization in terms of speed will follow soon. Therefore, the results have to be considered preliminary.

This White Paper builds on the White Paper "Accelerated Balloon Forming", which focuses on shorter balloon lengths.

Theory

Temperature Difference along the Heating Block

On longer heating block systems, higher temperature differences between the center and the edges are reported. Even though the effects are also present on short heating blocks, they become crucial for longer ones. Temperature differences are not compensated so quickly due to the longer distances.

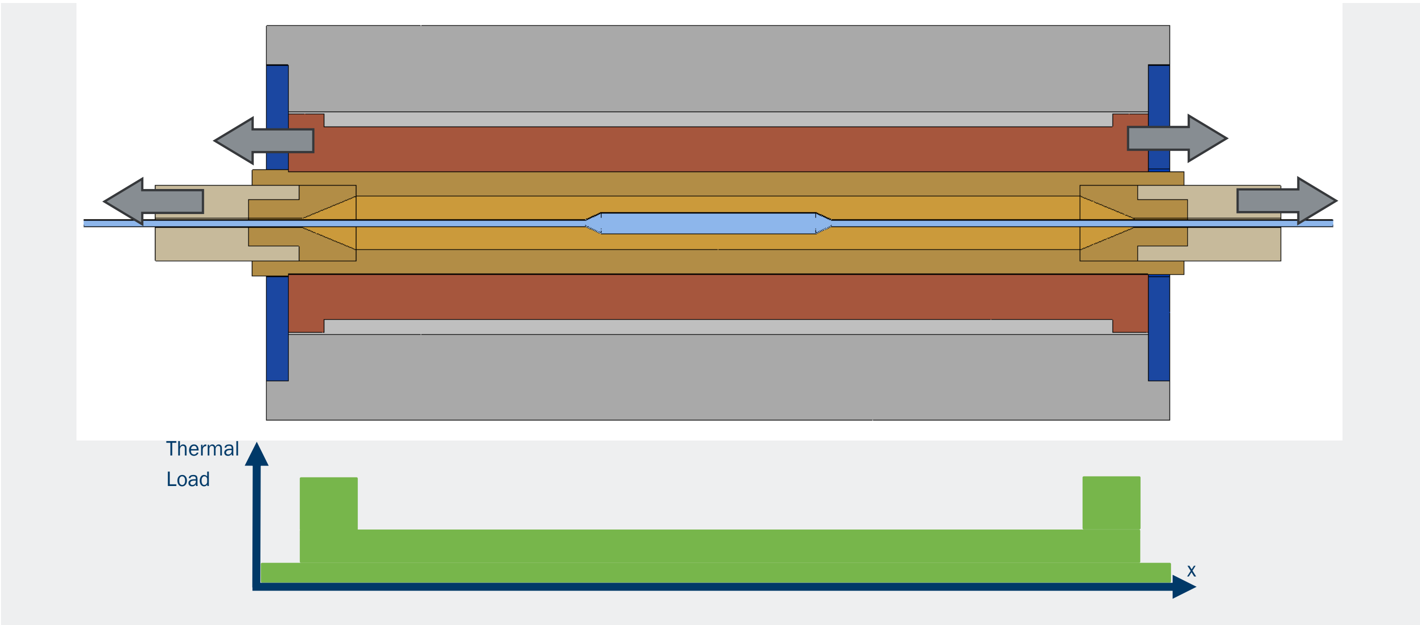

Figure 1: (t) Heating block with main heat losses and (b) the thermal load along the axis
There are two main drivers of the temperature differences:

- During the heat-up, the thermal load between the center and the edges differs significantly. At the edges, the cones need more energy to heat up than the hollow cylinder in the center part.
- In steady state, the temperature difference is driven by the heat losses. They mainly occur on the edges of the heating block.

Existing systems are compensating for these effects.

The following aspects play into the temperature distribution:

- Material of the heating jacket: an increased thermal diffusivity allows a quicker heat transfer and therefore more uniform temperature distributions.
- Isolation material and design help keeping the losses as small as possible.
- Heating cartridges can be fine-tuned, and a power distribution can be applied to account for different thermal loads. Due to the changing thermal loads for different balloon diameters and length, this concept has some limitations.

Control Concepts

There existing two basic concepts:

- **Single control system:** the heating is done with cartridges covering the whole length of the heating block. This concept was limited in the past by the manufacturing possibilities for very long heating cartridges. The power distribution is optimized along the axis to compensate heat losses. The temperature of the heating block is controlled at the center of the heating block.
- **Dual control system:** the heating is done with cartridges coming from both sides of the heating lock. The short heating cartridges are easier to manufacture. Each side of the heating block can be controlled individually. The power distribution is optimized as well to compensate heat losses. However, there is an unheated zone in the center of heating block due to the design of the cartridges itself.

In addition to that, a new concept was developed allowing to improve the temperature distribution.

Measures & Method

To improve the temperature distribution, a different heating jacket material with a higher thermal diffusivity was used. The geometry of the heating jacket was improved to allow a smooth dry out at the end of the heating process.

Furthermore, a sophisticated control concept with optimized heating cartridges was designed.

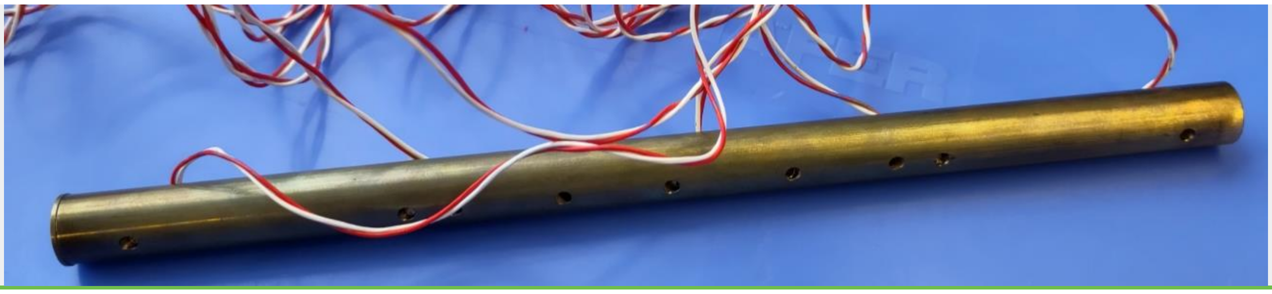

Figure 2: (l) Five-point temperature measuring probe.

The systems were tested by using a five-point measuring probe. This allows to see the spatial distribution of the temperature.

The heating blocks were heated-up to 155°C, kept constant until steady state is reached and cooled again. These high temperatures pronounce the differences between the systems. The heat losses depend on the temperature gradient between the heating jacket and the surrounding. The temperature is higher than what is usually used in balloon forming processes. Therefore, the effects are overestimated.

For these experiments, a 14.3x250mm heating block was used.

Results

Single Controlled Heating Block

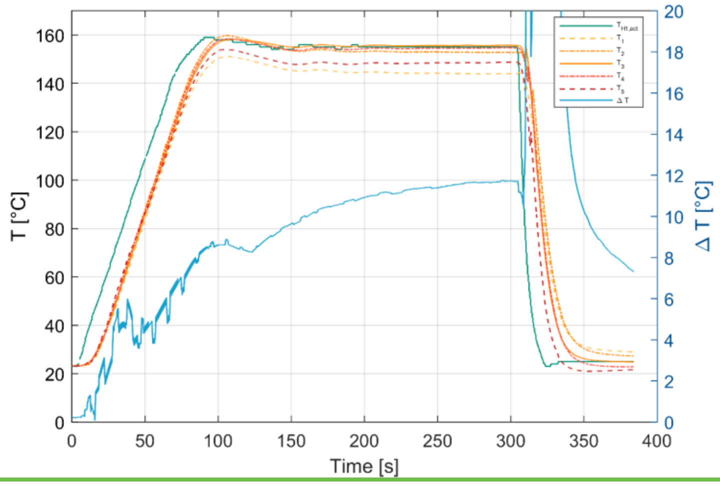

Figure 3: Timeseries of the step response to 155°C for a single controlled heating block.

The temperature distribution is very narrow during the heat-up. Steady state is reached after **approximately 150 seconds**. Then, the temperature difference has increase significantly and reaches more than **10°C** towards the end of the experiment.

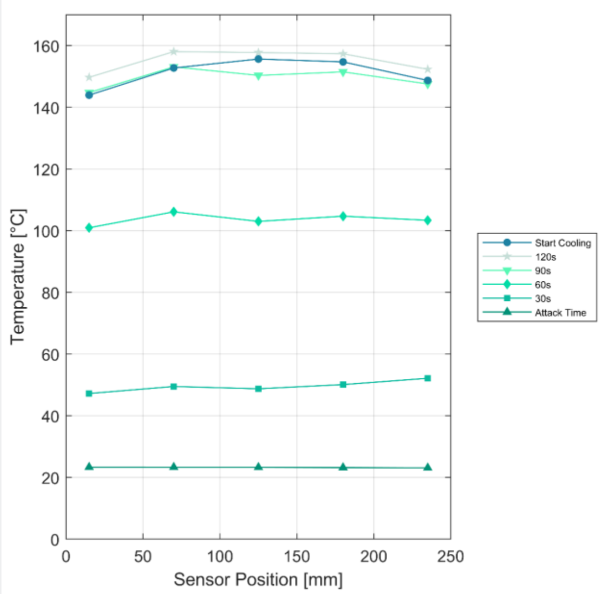

Figure 4: Spatial distribution of the temperature for a single controlled heating block.

The very uniform temperature distribution during the heat-up can be seen in **Fehler! Verweisquelle konnte nicht gefunden werden.**. However, once steady state is reached, the temperature distribution has increased significantly. The edges are cooler than the center.

Dual Controlled Heating Block

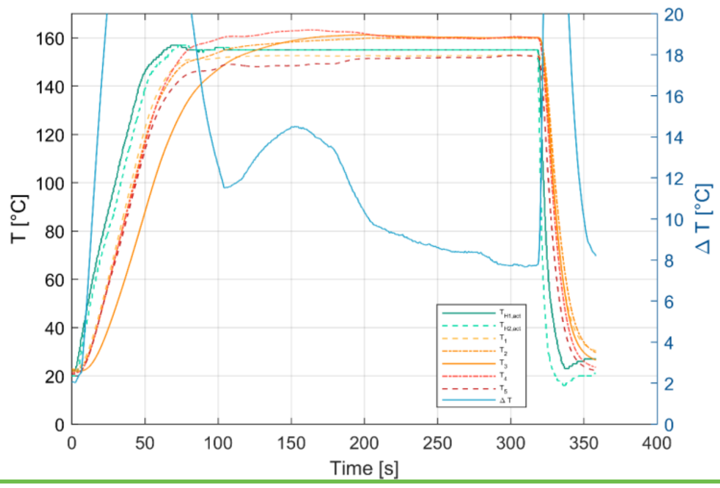

Figure 5: Timeseries of the step response to 155 °C for a dual controlled heating block.

The differences along the heating block during heat-up are very high. Steady state is reached after **approximately 200 seconds** and the temperature difference decreases to **eight degrees** towards the end of the experiment.

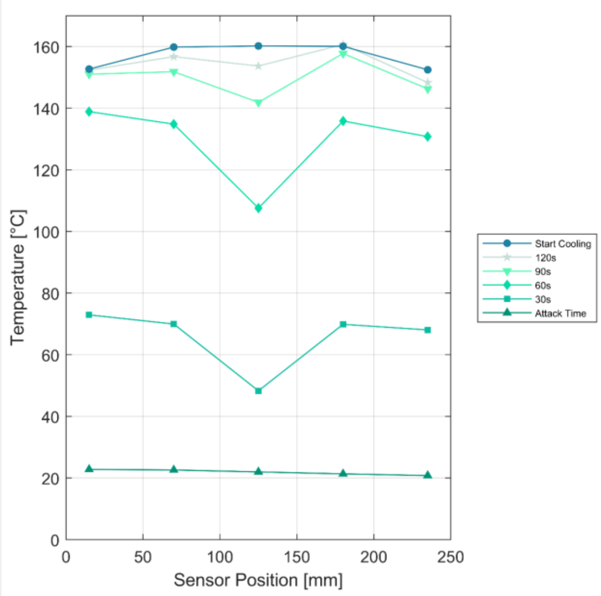

Figure 6: Spatial distribution of the temperature for a dual controlled heating block.

During the heat-up, the unheated zone in the center of the heating block affects the temperature distribution strongly. The center is heat-up much slower than the edges. In contrast, once steady state is reached, the temperature distribution sees less divergence at the edges than the single controlled concept.

Rapid Heating Block

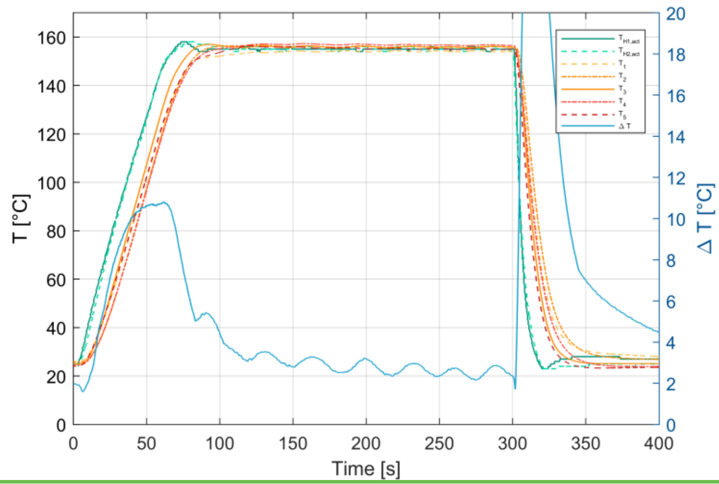

Figure 7: Timeseries of the step response to 155 °C for a rapid heating block.

The temperatures are quite uniform during the heat-up. Steady state is reached after approximately **125 seconds**. The temperature difference drops to approximately **two to three degrees** towards the end of the experiment. The PID parameters are not tuned to the end, a slight oscillation can be seen.

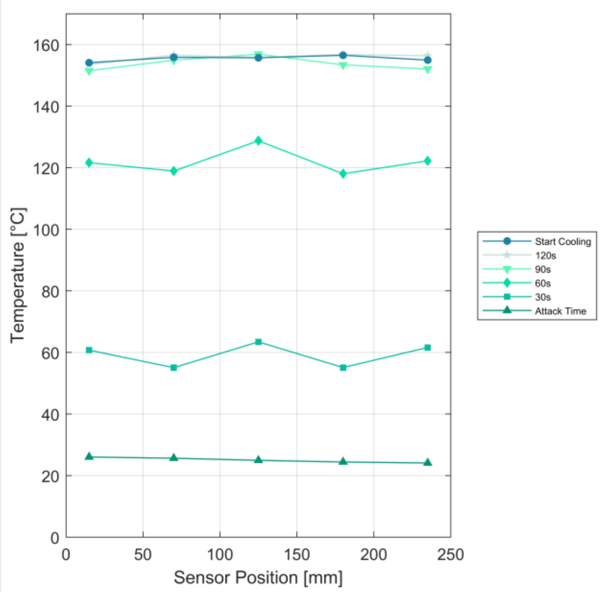

Figure 8: Spatial distribution of the temperature for a rapid heating block.

The temperature distribution during heat-up is more uniform than for the dual control system but less than the single control system. During steady state, however, the rapid heating blocks shows by far the best results.

Discussion

The single controlled heating block has the best temperature distribution during heat-up, however the worst in steady state. The dual controlled heating block sees a significant effect of the unheated zone in the center, however, during steady state, this concept is superior to the single controlled heating block. The newly developed rapid heating blocks shows a reasonably good temperature distribution during heat-up, even though in can not match the single controlled heating block. In steady state, however, the rapid heating block outplays all other concepts by far.

Conclusion

The rapid heating block offers the best trade of between the best possible temperature distribution during heat-up and the same during steady state. Later temperature distribution shows a superior performance compared to all the concepts.

This performance should be verified once the heating block is going to be optimized in regard of power as well.

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