Design Simulation of a Camera Housing for Extreme Temperature Ranges

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ABSTRACT: We report on the design, potential construction, and simulation of a compressed air-regulated borescope camera housing. The camera housing contains a commercial USB borescope camera with built in lighting system. The design of the camera casing and its components are discussed in detail. Simulation results of the housing at extreme high and low temperatures are discussed along with the required supply air pressure for proper operation. The design was partially prototyped, but due to unforeseen circumstances, it could not be completed. The Climatic Camera can provide clear, live visuals inside an environmental test chamber. Video recordings allow for more accurate failure detection of the tested components.

KEYWORDS: Borescope Camera; Environmental Test Chambers; Temperature Regulation;

Contents

1. Introduction

Digital imaging is a field where fast progress has been made. Digital cameras often need to function under especially rough and demanding conditions when used to observe product reliability testing. Such conditions may include extreme temperatures, various pressure ranges, strong magnetic fields, vibrations, or ionizing radiation.

The project sponsor, Danfoss TurboCor™, requested a camera to operate inside of their environmental testing chambers to improve failure detection of the components they test. The current chambers do not have adequate visibility from the outside and also require human presence to monitor the tests. A digital camera placed inside the chamber will allow remote monitoring of the products inside. This camera has to withstand the extreme low and high temperatures of the tests (-40 to 160 degrees Celsius) for periods of up to 90 days. However, few cameras were found that could meet these demands while remaining cost effective. Therefore, a custom temperature-controlled camera housing was developed to encase a conventional digital camera.

2. Materials and Methods

2.1 Digital Camera

The digital camera selected for the design is a third generation USB borescope, autofocus endoscope camera manufactured by Teslong (model number: 8595768091). This model was chosen because of its low price, autofocusing capabilities, and built in LED lighting system. Specifications for the camera selected can be seen in Table 1: Specifications of the Teslong Endoscope Camera.

Table 1: Specifications of the Teslong Endoscope Camera

HD Video Capture	Up to 2594 x 1944 pixels
Focal Length	0.01m to 100m
Diameter and Length of Cable	14mm, 5m
LED Lights	4 (color: white)
Interface	Hi-Speed 2 in 1 USB/Micro-USB
Waterproof Level of Cable	IP67
Operating Temperatures	0°C to 45°C

The camera features 4 LED lights that can be controlled by a dial on the USB cable. This will provide adequate lighting to see the components. Additional lighting can be obtained by using the built-in appliance light in the environmental test chamber.

2.2 Camera Housing

The camera housing was made by welding together a stainless steel DERNORD sanitary weld sight glass and a two inch barbed hose adapter. Figure 1 shows the housing that was welded at the FAMU-FSU College of Engineering machine shop.

Figure 1: Camera Housing

The housing consists of a stainless-steel body. Inside of the housing is a helically swept air channel. The inner wall of the helical air channel is in contact with a solid copper sleeve, which is in contact with the body of the endoscope camera (Figure 2). The copper interface between the camera and the air channel will create an efficient thermal connection between the ambient temperature air flowing through the channel and the camera. This will enhance the uniformity of the temperature distribution of the camera. The supplied compressed air is assumed to be at ambient temperature, and the required pressure for the device will be determined by the properties of the insulation materials recommended and the results of the COMSOL simulations.

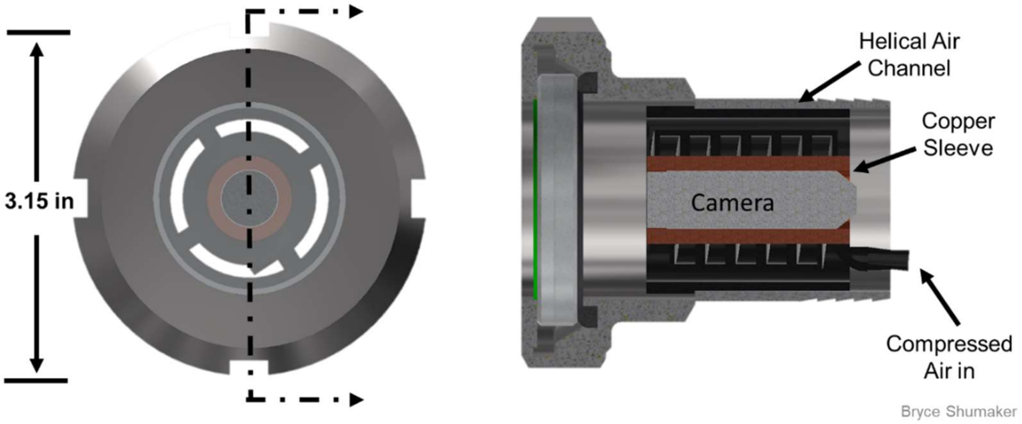


Figure 2: CAD render of camera housing: Left: Front view. Right:Cross section view with highlighted components

2.3 Temperature Regulation

To keep the camera within its operating temperature range (0°C to 45°C), active temperature regulation is needed. Since the camera is exposed to both hot and cold temperatures, compressed air is used as a medium to add or remove heat as needed. Compressed air is provided by Danfoss's central compressed air system. The compressed air is routed towards an air drying system. The air drying system consist of a desiccant filter to remove residual moisture from the air, and a built-in regulator to step down the main line air pressure to a desired pressure. This is then followed by a safety shut off ball valve which is connected to vinyl tubing to run to the camera housing. The schematic diagram of the internal connections of the system can be seen in Figure 3.

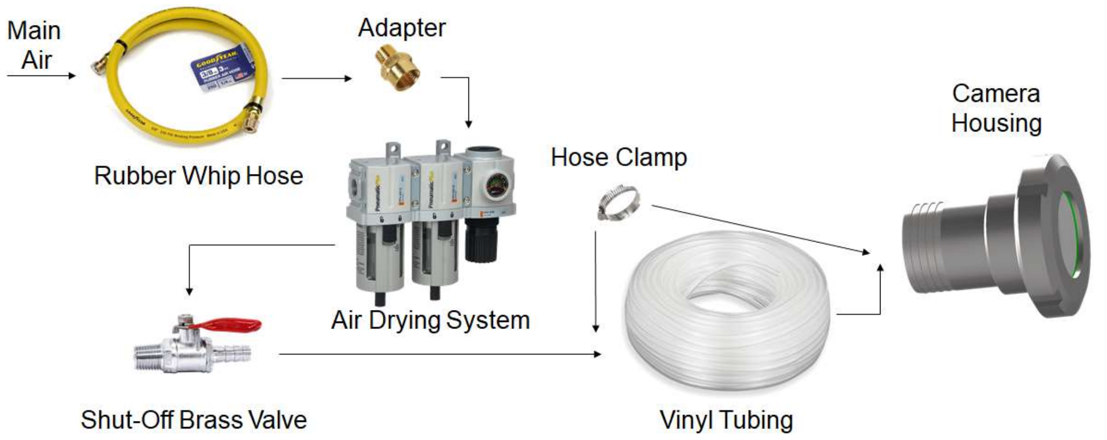


Figure 3 Component breakdown of the air supply for the Climatic Camera.

For exterior insulation, the housing is attatched to a suction and discharge hose that serves as the path for the air in and out of the housing, removing any unwanted heat. The dischatge hose is used to prevent leakages into the environmental testing chamber. Both the hose and the housing are to be wrapped in melamine foam pipe insulation, leaving the sight glass as the only exposed part. Melamine foam has isulation temperature that works for both extreme cold and hot temperatuers (-40°C to 176°C) with a resistance R-value of 5.12 and thermal conductivity k-value of 0.25. The pipe insulation is used to slow down the rate of heat transfer between the climatic chamber conditions and the walls of the housing. Figure 4 shows the shematic diagram for external temperature regulation.

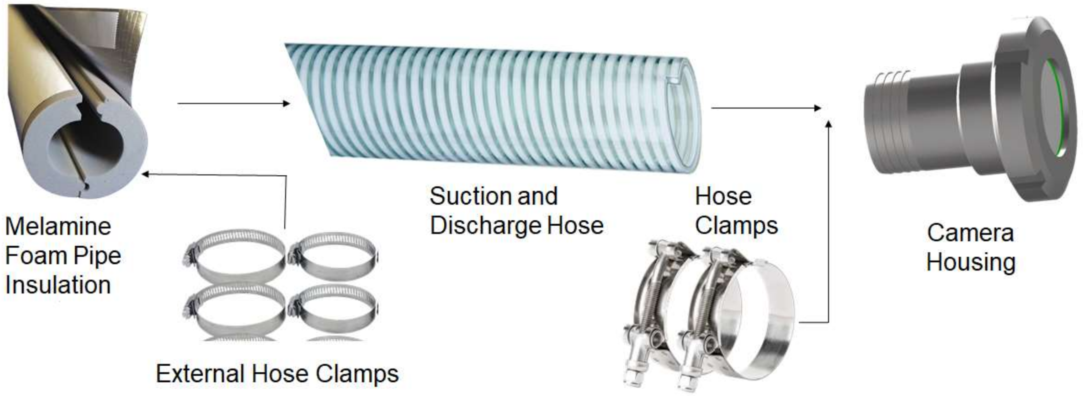


Figure 4 Component breakdown for outside temperature regulation (Insulation).

2.4 External Support

To improve failure detection it was required that the device be fixed at a desired location with a set view angle and distance. To do this we propose a 783 Newton (176 pound-force) steel magnetic base threated to a goose neck that can sustain up to 2.5 pounds at its maximum stress point. The goose neck is to be attached to a stainless steel plate with hose clamps that will be attached to the device to position at the desired location. Figure 5 shows the schematic diagram for the external support of the proposed solution.

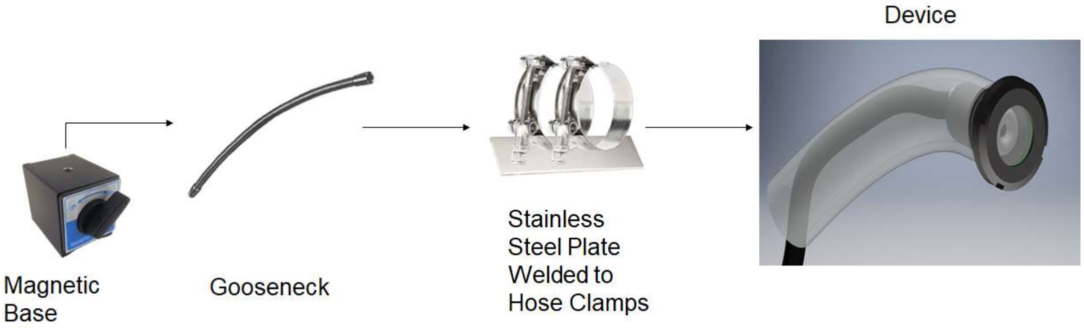


Figure 5 External support for fixed visuals.

2.5 Failure Detection

Finally, in order to ensure the device will be at operational temperatures through testing, a simple failure detection system is proposed. A micro-controller Arduino UNO is to be connected to the main computer where the test takes place. The micro-controller is connected to small temperature sensors that are placed inside the camera housing. Air exiting the housing is assumed to be the temperature of the camera. If such temperature gets within 5°C of operational limits (5°C to 40°C) an alarm speaker will be activated to indicate that visuals are at risk. Figure 6 shows the shematic digram for the failure detection system proposed.

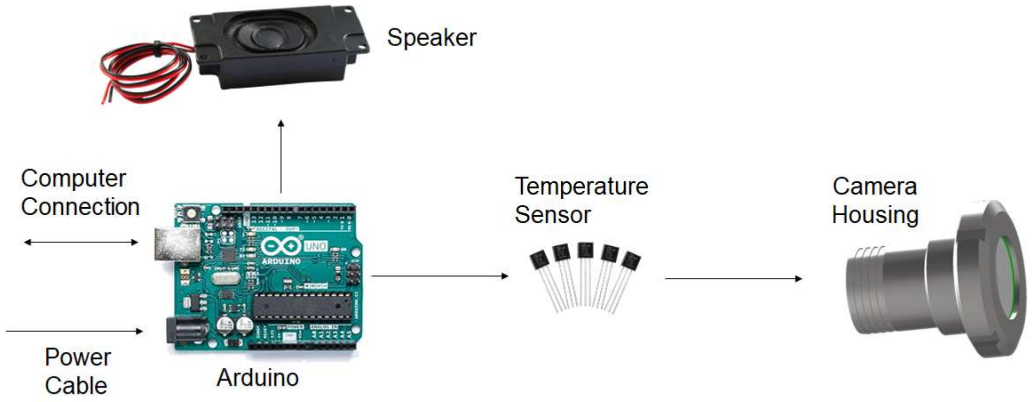


Figure 6 Device temperature failure detection.

3. Results and Discussion

Before the device could be tested for functionality, a simulation was done to see the required air flow for maintaining the temperature within the operational range. To do so, a model was setup in COMSOL using the L-VEL turbulence model for the computational fluid dynamics (CFD) part of the simulation, and the convective and conductive heat transfer were modeled in the steady state. Steady state was chosen for analysis due to the fact that the temperature difference between the camera and the extremes of the testing chamber will be at a minumum in steady state.

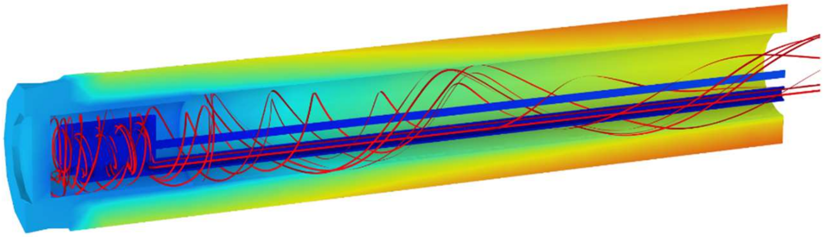
Boundary conditions for the CFD part of the simulation include the pressure at the inlet and outlet of the device. The inlet pressure was varied to examine the effects of doing so and to determine what the minumum pressure is to maintain operational temperatures for the camera. The pressure at the outlet was taken to be at ambient pressure, i.e, the gauge pressure was zero at the outlet of the device.

The boundary conditons for the heat transfer part of the simulation include: natural convection on all surfaces of the device exposed to the environment of the testing chamber, the air entering the housing is at ambient temperature, the air exiting will carry thermal energy out of the system with it, and the heat generation of the camera is negligible.

3.1 Simulation Results

Figure 7 illustrates the flow of air inside of the designed housing. Half of the housing was removed along the major axis for better viewing.

The air enters uniformly on the right side of the figure and makes its way to the helical sweep near the left side of the figure. The incoming ambient temperature air wraps around the camera and then it exits the air channel in the very front near the sight glass. The air then spirals towards the back of the device where it is exhausted to ambient conditions outside of the testing chamber. This spiraling effect of the air is a result of the helical sweep and aids in mixing the air inside of the device, avoiding any stagnant air pockets. Another advantage of the helically swept air channel is that it maximizes the surface area for heat transfer to occur between the ambient temperature air flowing through the channel and the camera it wraps around. This maximizes the heat transfer that will effectively regulate the temperature of the camera. Furthermore, once the close-to-ambient temperature air exits the helical air channel it acts to regulate the temperature of the other components, keeping them from exceeding their temperature limits before the air exits the system completely.



Nash Bonaventura

Figure 7 Streamlines showing the velocity field of the air within the housing.

Figure 8 and Figure 9 show the temperature distribution of the housing and its components for the four cases of interest. The simulations were tested at the high and low temperature extremes of 160 °C and -40°C, respectively. For each temperature extreme two different inlet pressures were tested to establish an acceptable lower bound for the pressure demand of the device for proper operation. The gauge pressures of 0.1 psi and 1.0 psi were selected based off of the results of abstract models and hand calculations.

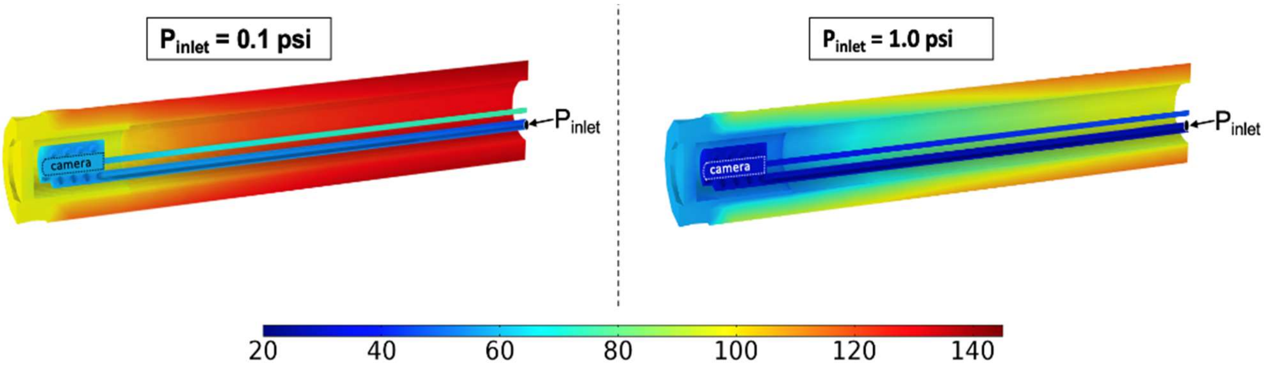


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Figure 8 Temperature distribution at 160°C.

The effects of increasing the air flow through the device are well observed in the figures and follow the findings of the initial abstract models.

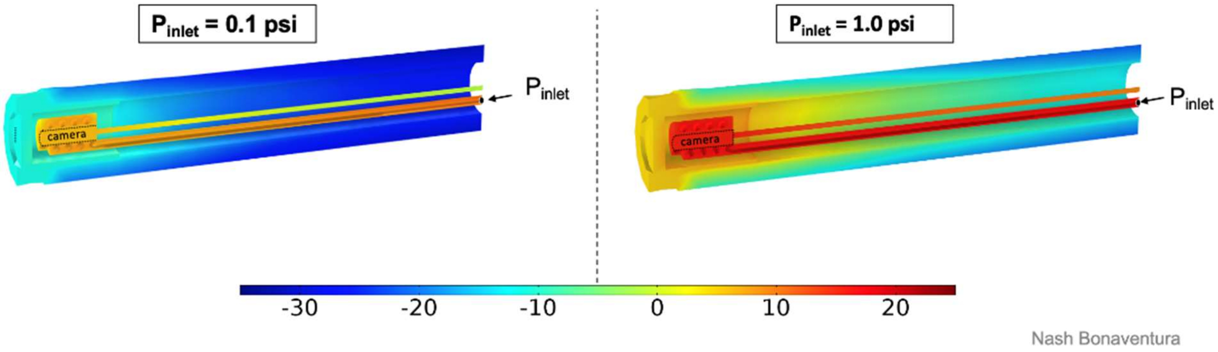

Figure 9 Temperature distribution at -40°C.

Figure 10 shows the bare camera and its temperature distribution for each case tested. This was the primary metric used to validate the design of the device. The target value for the camera temperature ranges from 0°C to 45°C. It may be derived from the figure that when the testing chamber is at the extreme cold temperature, the lower bound for the supply pressure may be reduced further than the lower supply pressure bound of the extreme hot temperature. These findings suggest the implementation of an active control scheme to monitor the temperature and throttle the pressure accordingly. However, this option was not investigated as it was slightly out of the scope of this project.

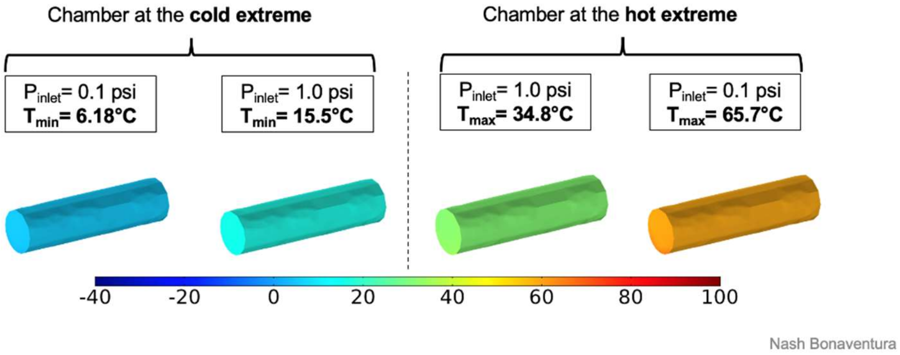

Figure 10 Camera temperature distribution for all cases.

4. Conclusion

Though we weren't able to build the physical protoype due to unforseen circumstances, it was proven through COMSOL simulations that our proposed device can withstand the extreme temperatures of the environmetal test chamber. Positive pressure and constant air flow inside the camera housing, allow our device to expel any unwanted moisture from potential leakages. Eliminating the threat of internal lens condensation. With constant air flow and a pressure 1.0 *psi* it was modeled that the surface of the camera stayed well within operational levels. The surface temperature of the camera at the chamber extreme temperatures (-40 and 160 °C) was simulated to be 15.5°C and 34.8°C respectively as seen in Figure 10. With our device, live continuous monitoring is possible without physical presence. Through our results, we have proven a succesful design that will help improve components failure detection for the Reliability Department at Danfoss during environmental chamber testing.

4.1 Prototyping

The final prototype was made using CAD to show how we envision our device. Figure 11 illustrates the proposed set up for improved failure detection.

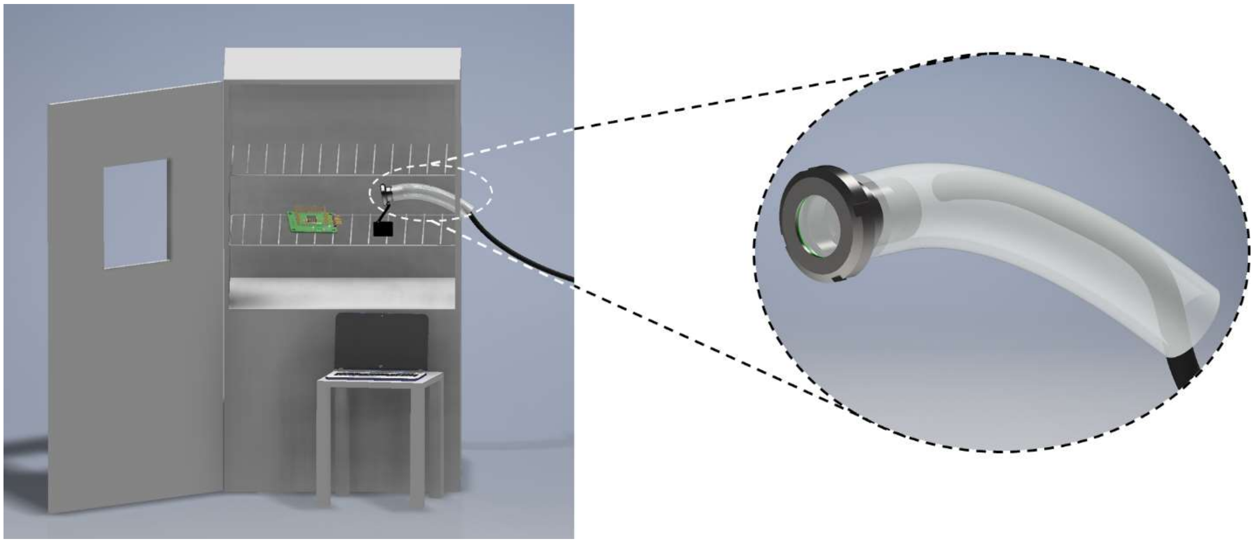

Figure 11 Proposed prototype set-up.