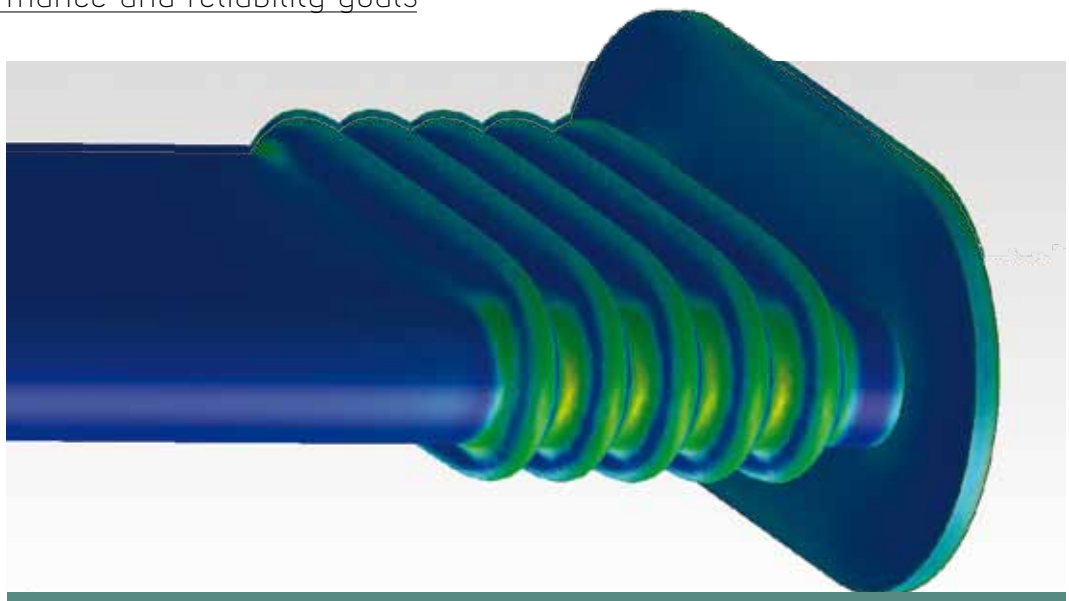
# Strength through flexibility

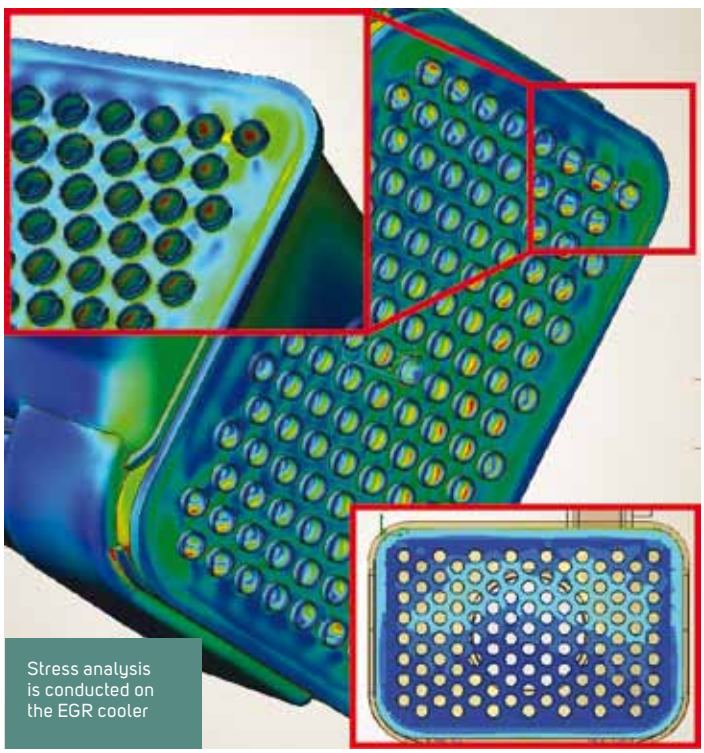
## EGR cooler designs are helping global OEMs to meet challenging performance and reliability goals

As emissions-related engine components continue to expand both in quantity and complexity, the market is demanding solutions that provide full transparency to the end user. This zero-impact approach when adding complex componentry leaves no room for compromises in durability or performance. Senior Flexonics has taken this direction seriously and has developed the experience and tools necessary to deliver products that exceed even the most demanding customer requirements.

Among emissions-related components, EGR coolers are some of the most complex and historically unreliable subsystems of a modern engine. Senior Flexonics saw customers struggling with these products nearly a decade ago and moved quickly to adapt existing technologies and expertise to provide a solution. Central to the design of these coolers was the use of thermal compensating tubes utilizing Senior's Bend-a-Flex tube technology.



Accommodating key aspects such as thermal stresses within design analysis is crucial to components maintaining reliability



Stress analysis is conducted on the EGR cooler

When evaluating EGR cooler durability, it is crucial to understand the different loading mechanisms and their causes within a general loading category – primarily thermal cycling. Thermal loading of EGR coolers falls into two levels that are typically referred to as thermal fatigue (high cycle) and thermal shock (low cycle).

High-cycle thermal fatigue is a more commonly discussed phenomenon, however it is difficult to understand its impact during the design stage due to the complexity of the structure. To assess damage, the loading cycles are counted throughout the normal application of the product and can often be approximated by looking at peak load swings over a given period of time or distance. The more challenging task is understanding exactly how to accommodate these thermal stresses within the component design. Unfortunately, these design lessons are often learned the hard way, with history witnessing product after product with massive warranty liabilities.

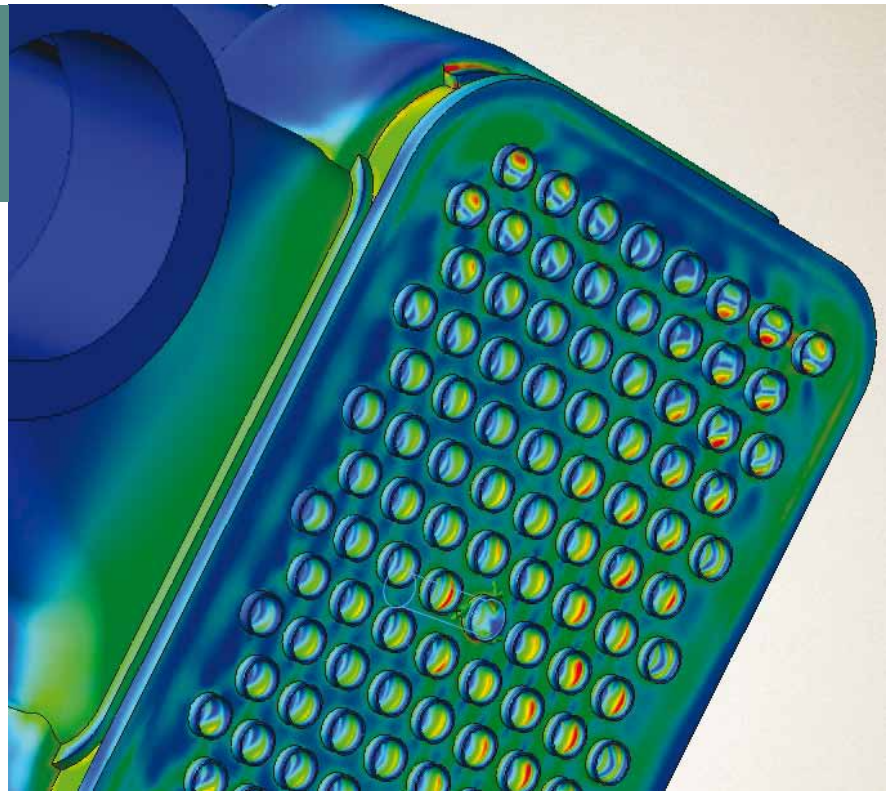
Within the design process, the only savior of the designer is the ability to lean upon robust analysis processes. Senior Flexonics understands this well and has invested heavily in an analysis team dedicated solely to EGR cooler development. This team has developed tools based upon lessons learned from a Bend-a-Flex field population approaching half a million EGR coolers. The modeling techniques are vetted against results of those existing products, as well as results coming from proven rig testing. The application of these analysis tools is the key component of Senior's competitive

advantage in fast and robust product development cycles.

The second thermal loading category is low-cycle thermal shock. This mode is experienced by the EGR cooler in non-normal running situations such as broken water pump belts, cooling line failure or aeration of the cooling system. In these situations, the boundary conditions that the EGR cooler is designed for start to break down, often resulting in runaway metal expansion that the structure cannot accommodate. The problem with non-normal operating conditions is that it is normal for most vehicles to experience these conditions over the course of the engine's life. Since many cooler designs can fail within seconds of coolant loss, it becomes unacceptable to expect an EGR cooler to require replacement after encountering these conditions.

These situations are where the base architecture of Bend-a-Flex sets itself apart from the competition. While stiff-tubed coolers can fail within seconds of coolant loss, Senior's coolers have survived events such as these thousands of times. Both rig and field-testing have shown nearly unlimited resistance to any cooling system issues the engine is capable of generating. One test shut off the water flow to the cooler and allowed it to boil dry under continuous hot gas flow. Coolant flow was then restored and subsequently shut off again, replicating an absolute worst-case field scenario. Competitor after competitors' coolers failed on this test within a handful of cycles; Senior's coolers were pulled off the test after thousands of cycles without any issue.

Other EGR cooler manufacturers have attempted to replicate these results with macro-compensating features such as floating cores or convoluted outer shells. These strategies, however, are fundamentally flawed because cooling systems do not see issues on a macro scale. Any of the above issues will result in non-uniform expansion of the gas tubes (typically starting with the upper tubes) rendering the macro-compensating feature useless. By utilizing individual flexible tubes, every passage within the tube array has micro-compensating abilities and accommodates thermal expansion independently of the rest of the tube bundle. This level of flexibility gives the OEM and the end-user independence from EGR cooler constraints, allowing for engine design flexibility features such as cold-side EGR valves, as well as the equipment uptime necessary to run a competitive business.



The high level of thermal shock resistance sets the Bend-a-Flex cooler apart from the rest of the competition

This level of thermal shock resistance sets the Bend-a-Flex cooler far apart from the rest of the competition. However, good companies understand the limitations of their products. When looking to smaller displacement applications, power density requirements can make the Bend-a-Flex cooler difficult to package in tighter spaces. In these applications, engine OEMs have been forced to compromise thermal shock resistance in favor of designs such as fin-in-tube coolers with inherently higher power density. While these designs can provide power density benefits, their tube passages are extremely stiff columns that expand without compromise under various thermal shock scenarios.

Senior recognized this difficult compromise as an opportunity. The engineering team was able to lean on the company's 100-year experience with flexible tubing along with extensive heat exchanger knowledge to develop an advanced fin-in-tube product that builds flexible features directly into the finned gas tubes. Through proprietary forming processes, each passage has convolutions formed directly to the tube enabling the same micro-compensation as discussed above on the Bend-a-Flex. This state-of-the-art EGR cooler technology can be found in Senior's newly developed Flex-a-Fin EGR coolers.

Within all of Senior's EGR cooler designs, flexibility is the key feature. Metal expansion is a simple fact within the abusive environment EGR coolers are applied in. Senior's engineering team believes that, as with most things in life, it is far better to accommodate change than to resist it.

Both rig and field-testing have shown that the very flexible Bend-a-Flex tubing technology from Senior Flexonics helps improve overall engine efficiency

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