A new approach, platform-based and modular, for conceiving , developing and manufacturing thermoelectric assemblies

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Abstract

Thermoelectric technology has a transversal and multipurpose character with respect to applications and it can lead to original solutions for a wide range of thermal issues and user's common thermal needs. The spread of thermoelectricity on many niche applications is hindered and slowed down by the difficulty to develop and industrialize thermoelectric assemblies which need a well balanced integration of thermoelectric modules, heat exchangers and heat sinks, and must be optimized in performance while also reaching a high quality level at a reasonable cost, even for the low-to-medium volume potential of each niche application.

The work will summarize the achievements of an original platform approach applied to the engineering of thermoelectric assemblies: a modular architecture made of a set of base components with common interface definitions, using the same thermo-mechanical coupling methods, ruled by the constraints of geometry construction guidelines and common assembly methods. Originally designed modular components are part of the platform's base set of parts as well as identified commercial components, that are all individually characterized with respect to the constraints of platform's architecture.

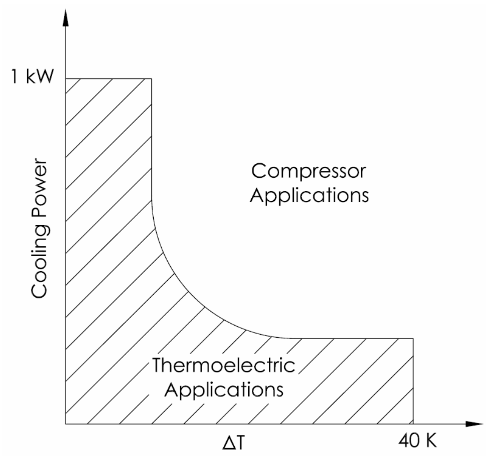
A proprietary mathematical model to predict performance of any assembly built out of the platform has been developed and is maintained together with a database of platform components' characteristics, properties and cost, thus permitting to conceive new solutions upon any special application's requirements, with accurate and reliable prediction of performance and manufacturing costs. Moreover, prototyping a new custom solution corresponds to just sampling a new combination of well known elements within the well known platform architecture, setting the premises for the shortest time-to-market for any new solution.

Introduction

The Peltier effect is one of the well known thermoelectric phenomena. Since the 1950's to now the technology has been developed and a lot of different kind of assemblies has been manufactured. The typical applications are related to cooling or heating environment in which the thermal power required was not higher than 1 kW.

They are generally applications where the common systems based on the compressor technology present some important limits. The low thermal power, for traditional equipments, are achievable only with a complication of the plant and with great reduction in terms of COP. Besides the problems related to the vibrations and noise are always present.

Figure 1: The typical range in which thermoelectric assemblies or compressor equipments can be prescribed.



A lot of possible thermoelectric applications can be realized to satisfy with an ad-hoc products different niches of the market. The problem related with the possibilities offered by the thermoelectric technology is that a single manufacturer must be able to produce a great variety of assemblies. For Peltech this is one of the reasons for the limited development of the thermoelectric technology.

This is the market that Peltech means to capture adopting the criterion of platform-product and the modular building of the device. This original approach has involved studies, experimentations and very important investments.

All Peltech assemblies are internationally patented.

The platform

The platform concept was developed from the requirement to obtain economies of scale both on the single components common to various products, and on the same process of device assembly.

The same process of the assembling is particularly important in our field since it guarantees quality and constructive repeatability and therefore expectable and repetitive performances of the assembly.

The platform represents a planning criterion in order to obtain a greater possible number of combinations of assemblies from minimum possible number of components. In this type of approach there are some limitations related to the planning, above all geometric, that can condition, in unacceptable ways, the development of the possible combinations.

Initially we have set some constraints:

1. the maximum current manageable by the electronic control is of the order of 40A;

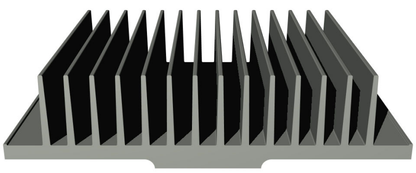
2. The base of the module (TUB - Thermoelectric Unit Base) device is characterized by:
   - Two thermoelectric cooling modules
   - Two heat exchangers (cold side, hot side)
   - An electrical modular circuit that enable a series or parallel connection
3. The geometric dimension of the parts production utilized to assembly the TUB. This choice allows the use of components with greater availability and wide range of performances on the market.

In collaboration with the Politecnico of Milan a different kind of thermofluid-dynamic numerical simulation has been made up to analyze the performance of compact finned and liquid heat exchangers.

It has been designed and realized:

A. a compact finned heat exchanger (Al 99,5%) with particular design of the fin, assembled with a patented technology.

B. air extruded heat exchanger (Al 6060) corrosion free and with negligible ionic release in aggressive atmosphere.



C. liquid extruded heat exchanger (Al 6060) with same physical characteristics as mentioned above.

D. a plate extruded heat exchanger (Al 6060) with same physical characteristics as mentioned above.

It is possible to make any thermoelectric device, using every combination of the different heat exchangers, perfectly equivalent for the platform concept.

To solve the problem related to a quick assembly of the electric circuits it has been designed as a modular electric circuit.

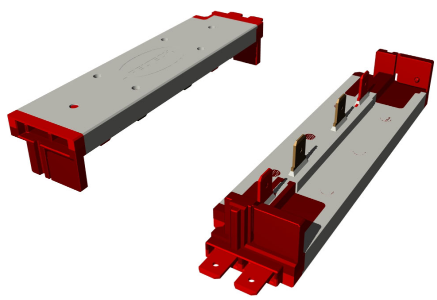
With this solution it’s possible to obtain different electric connection between the thermoelectric modules of the TUB and between the single TUB. The possibilities offered by this approach between the modules are:
- series
- parallel

and between the TUB are:
- series
- parallel

with only four modular electric circuits it is possible to realize all the electrical connections:
- series modules – parallel TUB
- series modules – series TUB
- parallel modules – series TUB
- parallel modules – parallel TUB

Every type of circuits is identified by a different colour.

Figure 2: Front and back view of the red modular electric circuit.



The clamping system of the TUB has been developed with the idea to solve two different kind of problems. The first one is related to obtain the correct pressure on the thermoelectric modules, and the second , the most important in an industrial process, is related to an easy and quick mounting. The idea was to use a special spring obtained by stainless steel band. The force applied on each single thermoelectric module is about 700 N.

Laboratory tests, in collaboration with Politecnico of Milan, have validated the effectiveness of such an assembling system as a result shock and vibration tests.

Figure 3: Stainless steel band spring

The thermal interface materials between module and the heat exchangers are graphite pads, on the hot side, and a material with changing phase with high thermal conductivity, on the cold side.

The performance of the device must be managed by an integrated electronic control. It was made with a PID logic control, with modulation PWM at elevated frequency, able to manage an electrical current until to 40 Ampere. The control is provided with a 8 kb microprocessor, which can be programmed according to the use of the assembly. The control board is characterized by two leds (green and red) that show the system status to the user.

To follow some Peltech's devices that show the concept of platform and modularity.

Figure 4: Liquid-to-liquid device (8 TECM)

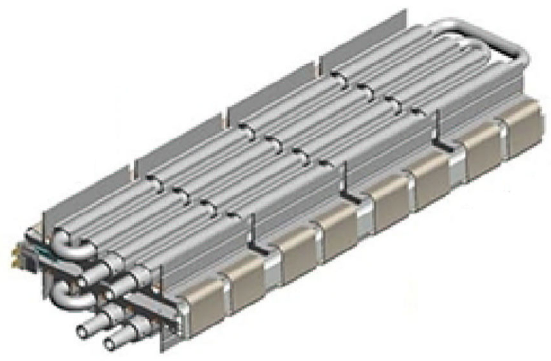


Figure 5: Air-to-liquid device (4 TECM)

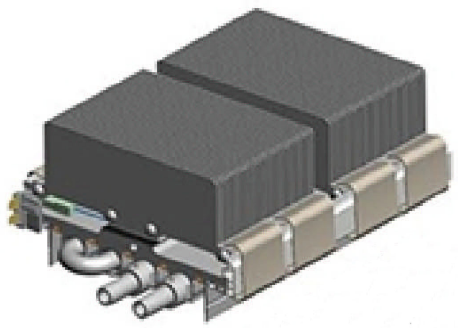


Figure 6: Liquid-to-air device (4 TECM)

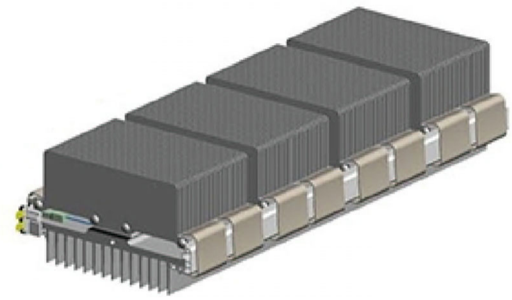


Figure 7: Air-to-air device (6 TECM): parallel-flow configuration

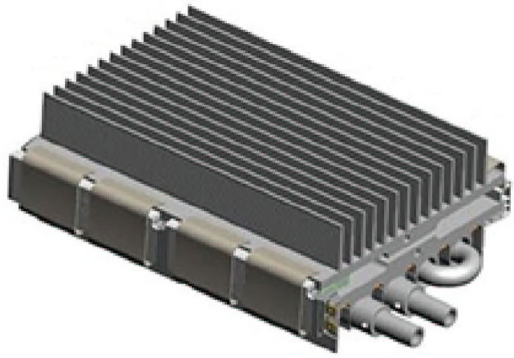
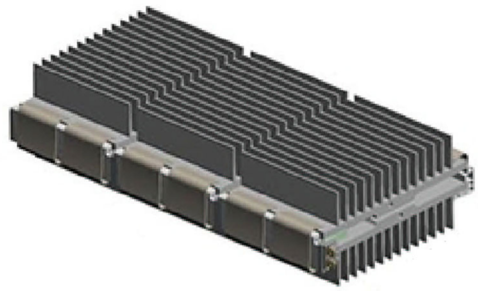


Figure 8: Air-to-air device (8 TECM): cross-flow configuration



Another plus of this kind of approach is to have few industrial machines to build up the all Peltech thermoelectric products. The quality of the assembly is kept constant during each step of the process production. In particular each TUB is assembled inside of a constant climate room (temperature and humidity) and controlling:

- the thermal interface quality with the "capacitor method".
- a fully integrated control to verify the correct load of springs.

Virtual platform tool

Each possible configuration can be well modelled by using a numerical approach. The numerical model easily gives the performances in terms of cooling power and temperature difference of the single assemblies. Peltech development a "virtual platform tool" (VPT) based on an experimental database of all platform components. The customers choose the product on the basis of :

- the kind of thermal exchange (air , liquid, plate);
- the maximum dimensions allowed;
- supply input voltage (generally 12 or 24 V);
- the maximum cooling power needed.

The VPT is able to predict the performances of assemblies changing only the components allow by the customer needs.

One of the most important peculiarity of our VPT is that all the thermoelectric performances are calculated considering the voltage (not the current) as the independent variable.

An example:

The actual thermoelectric air-to-liquid assembly (4 modules of 8.5A) is optimised with a 24V power supply. The performances of this thermoelectric device are:

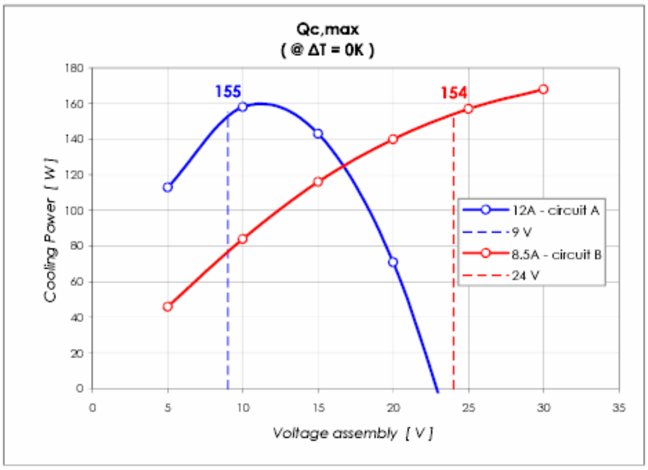
$Q_{c,max}$ = 154 W
ΔT_{max} = 25.2 K
COP_{max} = 1.17

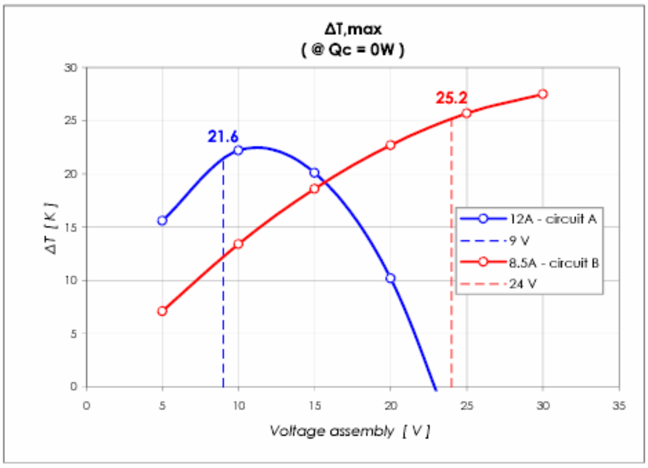
The customer needs an air-to-liquid with the same performance but with a 9V power supply.

With the VPT we can see the performance of the thermoelectric device using the 12A thermoelectric modules and changing the electric circuit:

$Q_{c,max}$ = 155 W
ΔT_{max} = 21.6 K
COP_{max} = 0.90

Chart 1-2-3: Detailed charts of both assembly in example. Performances ($Q_{c,max}$ ΔT_{max} and COP_{max}) as a function of power supply voltage (original device is show with the red line and the new device with the blu line).





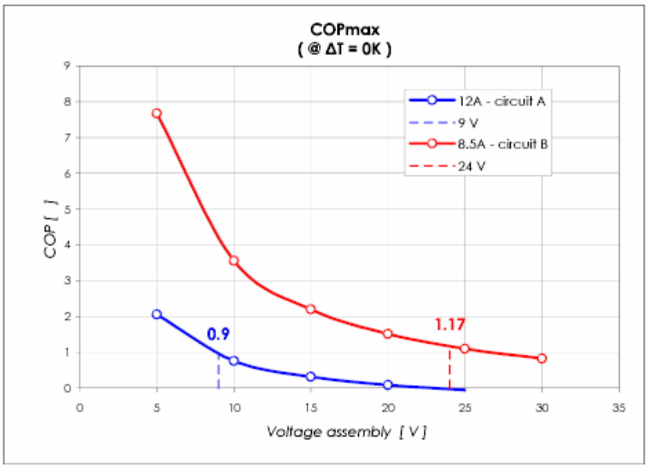
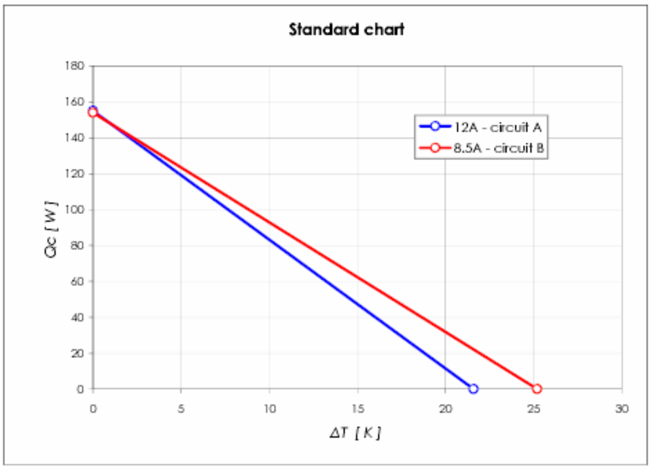


Chart 4: Standard chart of both assembly in example.



It's out of question that with this kind of approach we can easily and quickly spot the right solution to satisfied the customer need without making any real thermoelectric devices and experimental tests.

Future developments

All future developments will be lead by the expansion of the set of platform components in a way to continuously improve assemblies performances.

The evolutions are in the direction to obtain better performances in terms of the COP , Q_c and ΔT; to do this it is possible to follow two different ways:

- improvement of thermoelectric materials;
- optimization of heat exchangers, interface materials and all of the components except the thermoelectric module.

We think that many applications, for advanced products can be faced thanks to the quick time to market possible by a platform approach.

Conclusions

The development of such a platform was very expensive and it required a lot of time and higher investiments.

Nowadays, the challenge is the development of the thermoelectric applications and the setting-up of a market that can be made on a partnership basis with companies already operating in some specific sectors, who are willing to face innovative fields.

We are now working on many projects which show a renewed interest for the thermoelectric technology.

These technologies will never conquer the place they deserve unless we first off all define their limitations and advantages compared to compressor technology.

First of all, we must transfer all the basic knowledge to the customer to improve the best use of the thermoelectric technology.

References

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2. Rowe D.M., CRC Handbook of Thermoelectrics, CRC Press, 1995