IT'S ABOUT TEMPERATURE

PENTRONIC

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We're building the future – on sustainable values

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Employees with over 200 years of combined experience

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Critical environments secured by accurate measurement

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IT'S ABOUT TEMPERATURE

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Looking to the future

Pentronic is looking forward to an exciting time of development and change. Our journey has always revolved around temperature - measuring, understanding and optimizing to help our customers reach new heights. We know that accurate temperature measurement is critical for our customers' business, so it's important to have a partner who is sure to get every measurement right. It motivates us to constantly develop!

In this issue, you'll be introduced to some of our employees who represent what we stand for: long experience, technical expertise and tireless commitment. It is their competence, their innovation and their ability to solve complex technological challenges that have made us the leaders we are today.

To maintain our leading position and ensure sustainable development, we can now announce a new milestone in Pentronic's history – we are in the advanced stages of plans to build a new factory. This is not only an investment in our own future, but also a way of ensuring the long-term success of our customers. With more modern production facilities and increased capacity, we will be able to meet growing needs and demands even better. At the same time, we are also strengthening our position as a reliable partner in an ever-changing world.

"We are in the advanced stages of plans to build a new factory."

It is with pride and great anticipation that we look to the future. Our new factory is more than just a building – it is a symbol of our ambition to continue to grow and develop together with our customers. Together, we are creating the solutions of the future – and it is a journey I am proud to share with you.

Welcome to the next chapter in the history of Pentronic. Let's build for the future – together!

Claes Arnesson,
Managing Director

IT'S ABOUT TEMPERATURE

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Read more about temperature at Pentronic's website.

DID YOU KNOW THIS ABOUT **TEMPERATURE?**

The moon's huge temperature differences

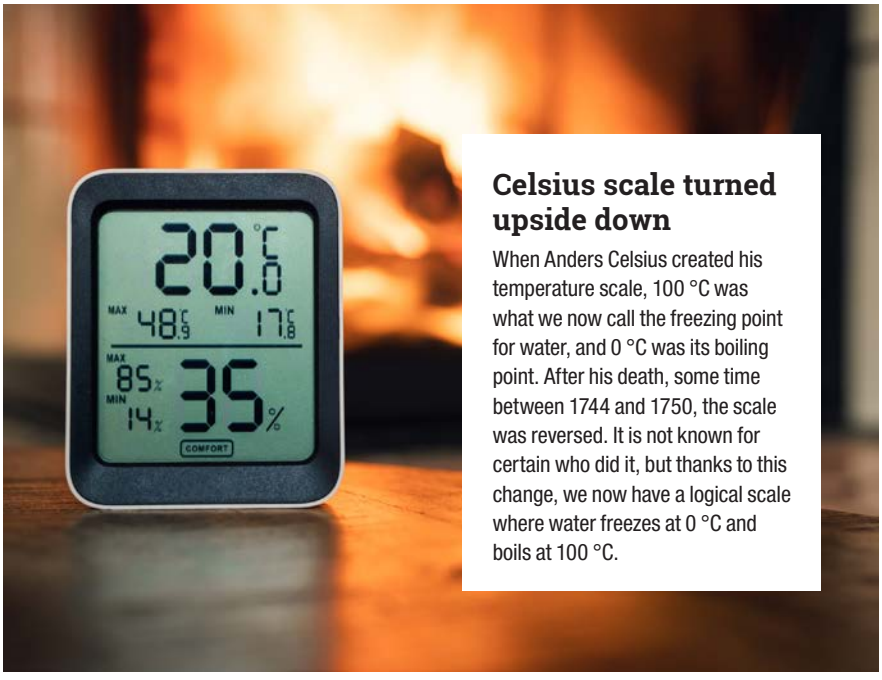
The Moon is subject to extreme temperature variations. When the sun is out, the temperature can rise to 120 °C, according to NASA. At night, the temperature plummets to as low as -133 °C. In some craters that never see sunlight, scientists have measured an icy -246 °C. That's colder than almost any other place we know of in our solar system.

The record day when winter turned into spring

We sometimes think the weather changes quickly in Sweden, for sure, but it's nothing compared with what can happen in North America. In 1972, in the city of Loma, Montana, the largest temperature change ever recorded occurred in a single day. In just 24 hours, the temperature rose from an extremely cold -47.8 °C to a more pleasant 9.4 °C.

Taking a dip cools you faster than you think

On a hot summer's day, it feels great to throw yourself into a lake or the sea. But bear in mind that the body loses heat much faster in water than in air – about 23 times faster! That's why the water feels so nice when you're hot, but it also means you cool down faster than you think, which can be risky if you stay in for too long.



Celsius scale turned upside down

When Anders Celsius created his temperature scale, 100 °C was what we now call the freezing point for water, and 0 °C was its boiling point. After his death, some time between 1744 and 1750, the scale was reversed. It is not known for certain who did it, but thanks to this change, we now have a logical scale where water freezes at 0 °C and boils at 100 °C.

How to avoid food poisoning

To avoid unfortunate food poisoning at summer barbecues and buffets, it's a good idea to keep an eye on the food. The simple rule is that hot food should be above 60 °C, and cold food ideally around 4 °C. This reduces the risk of bacteria multiplying and ruining the party.

The point where water does everything at the same time

There's a pretty cool point where water is able to coexist with ice, liquid and steam. It's called the triple point and it occurs at exactly 0.01 °C and a pressure of 611.657 pascals (about 6.11657 millibars). In thermodynamics, it's an important reference point for defining the Kelvin scale, the temperature scale that begins at absolute zero, 0 K. The triple point of water corresponds to 273.16 K.

Pentronic In Brief

Pentronic collaborates with and delivers to world-leading manufacturers in many industries. Examples include: food and food packaging, power generation, pharmaceuticals & medical equipment, vehicles & engines and the process industry.

Pentronic currently has

120

employees

10%

of our turnover is put back into development and innovation.

PENTRONIC

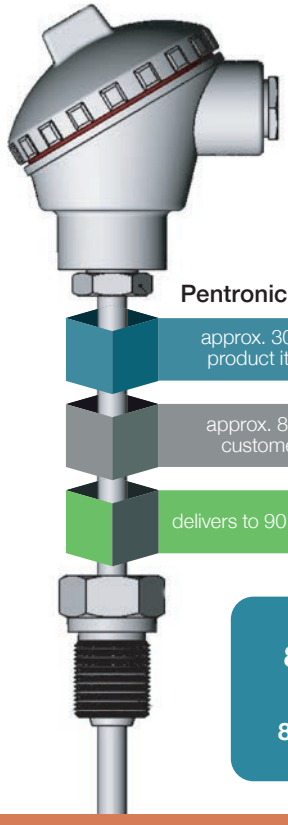
Pentronic has operated under its current name for 48 years.

6,69 %

Staff turnover in 2024: 6.69% including retirements.

35 YEARS

From 1990 onwards, Pentronic has been publishing magazines. In its current publication, *It's About Temperature*, the company shares information on customer projects, collaborations, technology news and its own organisation.



KARLSTAD

VÄSTERVIK

VERKEBÄCK

Pentronic has:

- approx. 30 000 product items
- approx. 8 600 customers
- delivers to 90 countries

Pentronic is dedicated and competent – together.

800 NEW PRODUCTS

Pentronic develops around **800** new products each year.

0,5 %

of employee working time is allocated to skills development.

4000

Since its launch, around 4,000 people have participated in Pentronic's training courses.

People

100% engaged people

- Employee engagement
- Leadership and skills development
- Diversity and inclusiveness
- Health and safety

Environment

CO_2 neutral

- Reduced CO_2 emissions (Scope 1 and 2)
- Increased proportion of renewable energy
- Energy efficiency
- Resource efficiency

Products & customers

Contribute 100% to sustainable customer value

- Customer satisfaction
- Sustainable innovation
- Products with a small carbon footprint

A Value System Centered on Sustainability

An important part of our sustainability efforts at Pentronic in 2025 includes placing extra focus on our employees and our core values.

"Sustainability has many dimensions and it's about so much more than just figures and carbon footprints. For us, it is about the people – it's the engagement of our employees and the competencies we hold that make a difference," says Managing Director Claes Arnesson.

Claes Arnesson.

Oscar Riis.

FOR ALMOST 60 years, we have helped our customers to develop and streamline their processes.

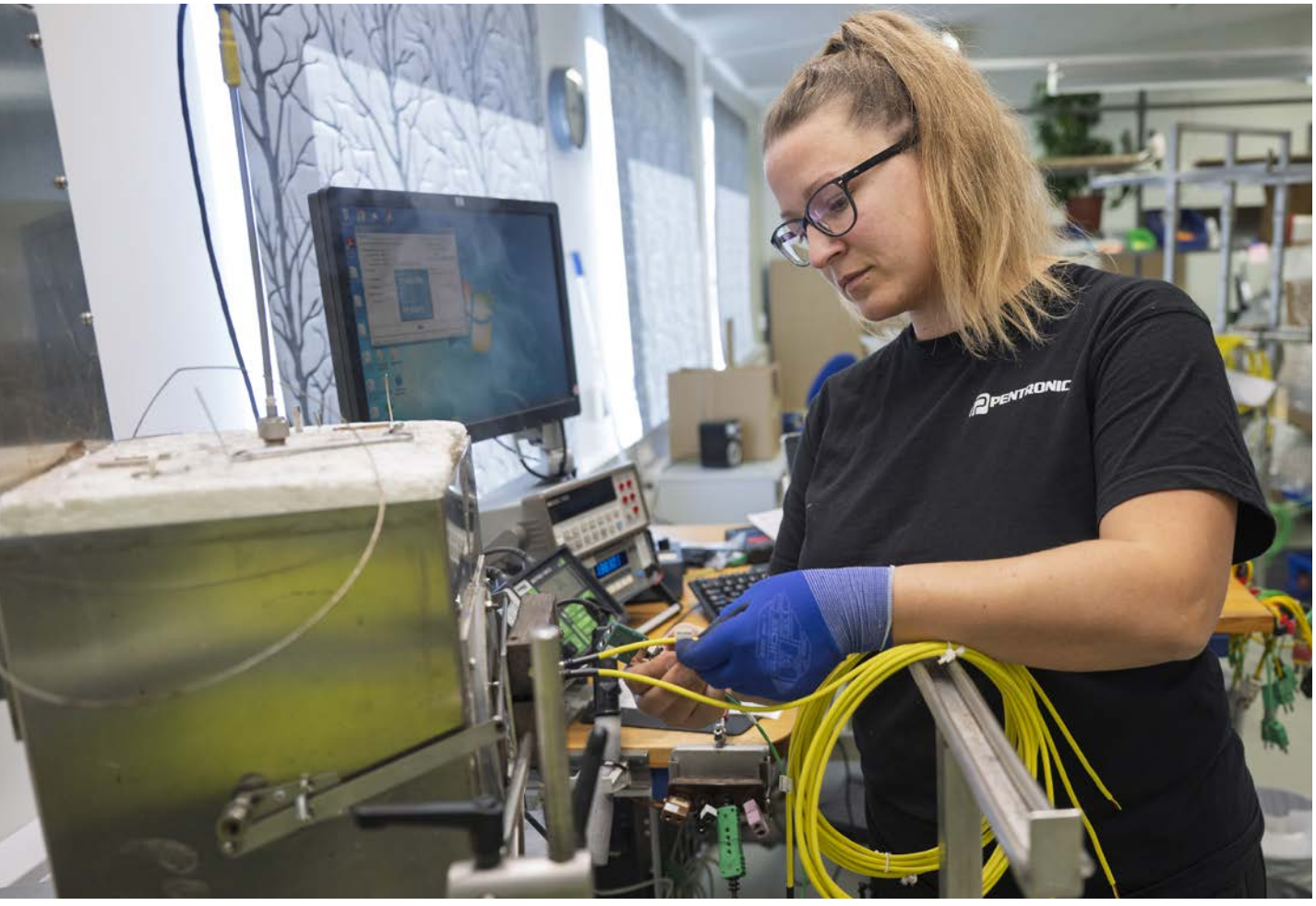
"Accurate temperature measurements are crucial to safety, quality and efficiency. As long as the laws of thermodynamics exist, we will have an important role to play," says Claes.

Our values permeate everything we do and include taking responsibility, supporting one another, sharing knowledge and developing – together with one another and with our customers. Here, we solve our problems side by side. It comes down to building trust. Trust between colleagues. Trust between us and our customers. We are a strong and close-knit organisation where everyone plays their part. That is how we grow – both as people and as a team.

Temperature measurements are crucial

It all started in a little garage. A couple of visionaries with a shared idea: What if temperature measurement could be more than just an aid? What if it were a way to create peace of mind, precision and reliability when it really matters?

Ever since then, we have been moving forward, one degree at a time. We are based in Västervik, Sweden, and live by the conviction that precision is more than just exact numbers – it's about measuring



the right thing, in the right place and at the right time.

Accurate temperature measurements are critical in everything – from ensuring that steel is made strong to making sure that milk lasts for longer and that reactors are running safely. When the margins are small, the measurements must always be right.

Why customers choose us

We have grown over the years, but we have always held on to our core values. It is our employees who make Pentronic a natural partner when precision is what matters the most. It is their engagement and expertise that ensures the measurements in our products are reliable.

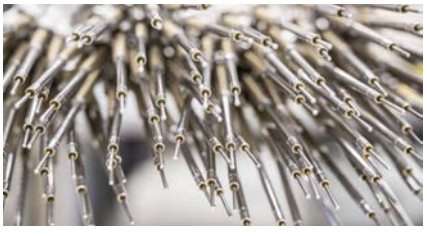
Together, we are driving development forward and will meet the challenges of the future with the same determination as when we first began. The trust we have built up over the years is something we carry with pride. We nurture it, refining the details and tending to our relationships – because we know that every degree makes a difference!

Quality through responsibility

At Pentronic, the working day is characterised by variation and flexibility. No products are alike, and this makes our job both enriching and fun.

"We find that quality benefits when our employees are able to take a high degree of responsibility in the process. This drives engagement and fosters a sense of pride in what we deliver," says Oscar Riis, Head of HR and Sustainability.

"At the same time, this can also pose a challenge when we are recruiting, but it also means that we get highly qualified and driven people coming into the company," says Oscar.



WANT TO JOIN THE TEAM?

At Pentronic, we are constantly looking for new colleagues who want to join us on our journey.
We operate within a broad area of expertise, and as a part of Indutrade, you will gain access to both development opportunities and a large international network.

Sound interesting? Get in touch or send us an open application via **pentronic.se**

New **Facility** in Sight

Pentronic has exciting plans to build a new manufacturing plant in order to unite all operations under one roof.

"I'm glad that everything is now beginning to fall into place," says Managing Director Claes Arnesson.

Pentronic's new centralized production facility will be constructed in Västervik to serve the company's entire operations. (The image is a conceptual rendering.)

TODAY, PENTRONIC'S production is divided across two units – one in Verkebäck and another in Västervik.

"The need for new and more suitable premises has only increased as we've become more and more pressed for space over time. Locally, we've made lots of short-term changes, but we need to optimize our production flows in order to better meet the demand for greater volumes," says Claes.

Building for growth

Preparations for a new production facility have been ongoing for several years now.

"It feels good that we've come so far along that we now have a potential plot in Västervik and we're looking forward to breaking ground soon," says Claes.

At the same time, Pentronic is also planning long-term for more growth and greater volumes.

"We currently have 120 employees and we're aiming to grow by about 30 percent.

"It feels great to have owners who believe in our future plans and the extensive competence that we possess here at Pentronic," says Claes, going on to add that:

"Many of our employees have extensive experience and solid knowledge that we really cherish. When it comes to the transfer of knowledge, we have lots to gain by bringing everyone together."

Many benefits

Some of the other benefits and synergy effects include the potential for a more effective and rational production setup. This will also facilitate the recruitment of new talent and help ensure the long-term supply of talent and skills. Plus, it is also good for the environment in that unnecessary transport journeys between units can be eliminated.

Safe and healthy working conditions are a fundamental prerequisite for the health and wellbeing of all employees.

"The new premises will provide us with an even better work environment and take us one step closer to yet greater satisfaction at the workplace. And because many of our employees live in Västervik, they won't have to travel as far to get to work. This saves time and reduces the need to drive, thus benefiting both the environment and health by enabling employees to walk or cycle to work," says Claes.

A strong corporate culture

Alongside this development, active efforts are also being undertaken to develop the company's brand.

"What this shows is that we're setting a clear direction for Pentronic in terms of where we're headed and what goals we have," says Claes.

For decades now, Pentronic has been developing measurement equipment for use in extreme conditions and critical processes – and it has become a guarantor of technical expertise.

"Our most important asset is our people and together we are driving Pentronic forward.

"We strongly believe in the power of our organization, and so it's important that we have a shared outlook and a strong corporate culture. This will become even more significant as we come together under the same roof. And so for that reason, we have initiated work on our brand image in good time, so we will be well prepared before the move," concludes Claes.

”It feels great to have owners who believe in our future plans and the extensive competence that we possess here at Pentronic”

Claes Arnesson,
Managing Director

Combined They Have Amassed **206 Years of Experience!**

One of Pentronic's greatest strengths is that many of its employees have extensive experience and solid knowledge within the art of temperature measurement. Below you will meet some of our longest-serving team members – Dennis Lundberg, Susan Stein Larsen, Mikael Eriksson, Göran Österberg and Per Bäckström – who all work at the P1 Unit in Verkebäck.

WHEN ASKED TO imagine what the future of Pentronic will be like in ten years' time, they all express a hope that the entire business will be gathered under the one roof.

"That would mean a lot – in terms not just of the environment, but also the efficiency of our work, time savings, and not least knowledge sharing."

Valuable Source of Knowledge

Combined, they possess an impressive amount of experience after having worked with temperature-measurement products for more than four decades. Passing on this knowledge to new employees is an important yet difficult challenge.

"The transfer of knowledge requires clear manuals and structures," says Mikael Eriksson, who has worked in many different areas over the years, from machining parts to manufacturing thermocouples. He also participated in the development of the P2 Production Facility in Västervik which was inaugurated in 2002.

"I have always enjoyed my work, especially because I am able to take responsibility for my tasks and work autonomously," says Mikael, and his opinion is echoed by the others.

They also speak of many appreciated customer meetings over the years.

"We have had customer visits to our production facilities and met with many customers in their own environments and processes," says Per Bäckström, Sales Engineer and Technical Expert.

The Pentronic Spirit

The work culture at Pentronic is characterised by engagement and a strong sense of cohesion.

"There has always been a family atmosphere and a great team spirit at Pentronic," says Göran Österberg, who has worked in most areas within temperature sensors and thermocouples.

"The Pentronic spirit means that everyone takes on a big share of responsibility, helps each other out and makes sure that the job always gets done on time. When we receive praise from a customer, we make sure that it reaches back to everyone," continue Dennis Lundberg and Susan Stein Larsen, who both work in the warehouse.

This positive atmosphere is also evident outside of work.

"Over the years we've become a close-knit group and we often do things together – from playing ice hockey on the frozen waters of Verkebäcksviken to group training in the gym at Gunnebo. We've been to concert at Gränsö Slott and we've gone on trips together," says Per.

"The fact we socialise in our free time has meant we've become real friends, not just colleagues," adds Susan.

How It All Began ...

Mikael, Göran and Dennis all began their journey at Albin Jansson's mechanical workshop, which manufactured thermocouples and temperature sensors. This company was later acquired by Pentronic.

Under the leadership of CEO Torsten Lindholm, the foundations were laid for the business as it exists today. From the outset, Pentronic has set its sights on developing its own products and solutions for the entire measurement process, placing particular focus on qualified temperature measurement for industry, research and development.

"In the beginning, we built many individuals products in small runs." A salesman would come into the production department with a handwritten note of a component's measurements," remembers Göran.

"As time went on, we got more bigger customers and our volumes increased, and so too did our requirements for delivery precision and quality." Manufacturing methods have also been developed and improved over time.

Orders Written by Hand

When Susan began working at the order office in 1987, all orders were written out by hand.

"We sent them to the warehouse using a tube system to save us from having to run up and down the stairs all the time. Extra pressing orders were marked with the word urgent," she explains.

Fridays were devoted to planning and briefing meetings with management.

"We would go through the coming week and receive information about any large orders. Many of the customers we had back then are still our customers today," says Dennis.

Key Investments

Pentronic has undergone several ownership changes since it began – something which the employees say has been positive.

"It has provided the business with security to have strong owners who are willing to invest. One example of this would be our transition from TIG welding to laser welding," says Per.

Important technology investments included the introduction of material and process management in the production department, as well as CNC-controlled machines.

"All of the machinery we use has been continuously modernised. Today, we manufacture virtually all components ourselves," explains Mikael.

The premises have been rebuilt and extended over time, and in 1988, the accredited calibration lab was added, which is now something of a heart for the business. Many have also pointed out the scenic location of the factory in Verkebäcksviken, a beautiful bay in south-east Sweden.

"When we had a delegation from China visit us in 2013, they wondered if it was actually allowed to have a factory in such a beautiful place," laughs Per.

"The location even means that employees have sometimes come to work by boat," conclude Dennis and Göran.

DENNIS LUNDBERG
– 41 year of employment

Position: Warehouse Worker.
Journey within Pentronic: He started in 1984 working on the production of sensors before then moving to the warehouse in 1990.
Lives: In Ankarsrum.
Hobbies: Fishing, mountain biking, gardening and music.
Fun Fact: He plays guitar in the hard-rock band Oden Force and they have recently released a new track on Spotify.

MIKAEL ERIKSSON
– 44 year of employment

Position: Assembler and Team Coordinator.
Journey within Pentronic: He started in 1981 machining parts before then moving on to thermocouples. He then became a team leader and participated in the construction of P2 in Västervik.
Lives: In Västervik.
Hobbies: Hunting, carpentry, woodworking with friends and cooking.
Fun Fact: His favourite dish is Kronkalvsentrecôte (venison).

GÖRAN ÖSTERBERG
– 42 year of employment

Position: Production Engineer.
Journey within Pentronic: He came onboard in 1983. He has worked as a team leader, design engineer and production manager.
Lives: In Västervik.
Hobbies: Exploring the archipelago – he now has a motorboat after many years of getting about by sailboat. He also likes cycling in nature.
Fun Fact: He has a holiday home in beautiful Österlen.

SUSAN STEIN LARSEN
– 38 year of employment

Position: Warehouse Worker
Journey within Pentronic: Susan started in 1987. She worked in the order office for 18 years before moving to the warehouse.
Lives: In Gunnebo.
Hobbies: Going for walks, spending time with family and friends and travelling.
Fun Fact: She is now retiring after 38 years with Pentronic.

PER BÄCKSTRÖM
– 41 year of employment

Position: Sales Engineer and Technical Expert.
Journey within Pentronic: He started in 1983 in the electrical workshop before then becoming a service technician and finally a sales representative.
Lives: In Västervik.
Hobbies: Technology, cycling, travel. Active in the Pentecostal Church and his housing association.
Fun Fact: He saw the big five – a lion, buffalo, elephant, leopard and rhino – on a safari in Tanzania earlier this year.

Carolina Åberg,
BA Head of People, Indutrade

Collaborating to Create a **Sustainable Workplace**

Sustainability is not just about the environment and business – it's also about nurturing employee health and well-being, so everyone can thrive and develop long-term. "Focus on the People is one of our core philosophies at Indutrade. Our employees are the most important asset we have and the key to the group's development," says Carolina Åberg.

SINCE NOVEMBER 2024, Carolina is BA Head of People at Indutrade with responsibility for the business areas of Life Science and Technical Systems & Solutions, which includes Pentronic. She has extensive experience with both strategic and operational HR roles.

Oscar Riis has worked in HR at Pentronic since 2021. In February 2025, he was appointed HR and Sustainability manager.

"All employees play an important role in our sustainability efforts. It is among one of the most important things we can work on in order to continue being successful," says Oscar.

Engagement generates development

One of Indutrade's strategic goals is one hundred percent engagement among employees, something that is clearly evident at Pentronic.

"There is a huge level of engagement here, both in relation to customers and to developing the business. Our employees are the most important asset we have," emphasize Oscar.

A core element of the sustainability efforts at Pentronic is continuous improvement.

"Our employees come to us with many good suggestions. One example is that we now supply menstrual products at the workplace. Environmental issues also spark engagement. Among other things, we are looking at how we can reduce our plastic consumption at work. Small efforts make a big difference over time."

A safe and healthy workplace

A good working environment is fundamental to workplace satisfaction and long-term well-being.

"Employee health and safety is always our highest priority. Indutrade has a vision of zero accidents and works actively to improve the work environment. It is up to the managers in each company to create a sustainable working life, and we are each other's work environment," says Carolina.

"Our employees and managers have an important role to play in that work, too. Together,

Oscar Riis, HR and Sustainability Manager at Pentronic.

"There is a huge level of engagement here, both in relation to customers and to developing the business. Our employees are the most important asset we have."

Oscar Riis

we work to create a healthy workplace with good work-life balance. Alongside improving the work environment and ergonomics, we also prioritize wellness," continues Oscar.

Focus on sustainable development

Carolina highlights the positive corporate culture at Indutrade.

"There is a clear set of values here and a structure that reflects long-term thinking. The companies are run under a successful model characterized by entrepreneurship and decentralized leadership with a focus on sustainable development.

The new group structure at Indutrade facilitates collaboration between companies with similar technologies and operations.

"It is valuable for us to be able to support each other, share knowledge and draw on each other's experiences," says Carolina.

Indutrade's support is also valuable when it comes to matters such as diversity and equality.

"At Indutrade we strive to be all-inclusive in everything we do, and we make sure to employ a broad representation of personnel with a focus on gender equality and diversity. We are constantly working towards this goal, although there's always room for improvement."

"Pentronic has come on a long way in this work. They have an open corporate culture and they pursue these issues in an inclusive way together with their employees," continues Carolina.

Development and growth

One challenge for Pentronic is finding new employees as the company grows.

"When recruiting new talent, it's important to make sure everyone gets off to a good start and that they have the chance to learn about our culture and values," says Oscar.

Pentronic invests in training and internal development.

"We want to give our employees the chance to grow in their roles or to take new steps.

"At the same time, it's also important that we maintain the high professional standards we have within the company. Knowledge transfer is a challenge we work with on a daily basis. We need organizational learning in place and we've done a lot of work on this already, but there is always more to be done," says Oscar.

Carolina agrees, adding: "There is a lot of expertise within Indutrade and it is important that we protect it. So it's great to see the companies working actively to transfer and safeguard knowledge."

INDUTRADE

Indutrade is an international technology and industrial business group that today consists of more than 200 companies and has over 9,600 employees around the world. The company develops, manufactures and sells technology products and services within selected niches.

Craftsmanship Meets The Future

– A Delicate Balance As Production Develops

Anna Jordan and Alen Muminovic are Production Engineers. "Working with employees to solve various challenges and watch as improvements make a difference is highly satisfying," they state.

SOLID GROWTH MEANS new challenges for Pentronic – not least when it comes to ensuring a long-term supply of talent.

"It's important to accelerate but slowly, and to set aside time for the training and development of new employees. A huge challenge as our volumes increase is that we can't just buy off-the-shelf machines and equipment that are ready to go. We use a specific manufacturing process that requires custom machines," says Alen Muminovic.

"Since our production is mostly manual we must be aware of the considerable craftsmanship that our production personell pocess as we standardise our working methods. This is something we need to protect as we grow," he continues.

"Fundamentally, it's about finding the best way to produce our products – a model that combines how we have worked historically at Pentronic with new ways of doing things," says Anna Jordan.

Our People Are our Stars

As a manufacturing support function, the manufacturing engineering departments focus is on the development and continuous improvement of the production process regarding methods, machines and processes.

"We collaborate closely with our production department, and everyone shows a huge amount of engagement as we work together to implement various improvements. We also collaborate closely with other support functions, such as the Electronics R&D team, production planners, design engineers and quality," explains Alen.

"By working together in this way, we can develop our production flow and processes and identify where we need to invest in new machines and equipment," continues Anna. She also emphasises that their employees are the stars of their day-to-day work. "Together, we want to facilitate their daily workflows, create a rational and efficient production process and reduce wastage."

A Successful Approach

Alen and Anna appreciate the huge overhaul they have seen in their work.

"It's really cool to come to work each day and see that we've been making a difference by helping each other to resolve difficult challenges. I also love that I get to be creative at work" says Anna.

As production engineers work across a very broad area, they need to possess considerable knowledge about the materials and production flows used, as well as the machines and tools and how they function.

"We are working hard to standardise out working procedures, develop new flows and acquire new equipment. Together with production management, we are responsible for machine and method instructions and for training," says Alen.

"Our work also encompasses the work environment and ergonomic improvements. A welcome change that has just been implemented is that the work area for the manufacturing of P100 has been doubled to 75 square metres and kitted out with new height-adjustable tables," concludes Anna.

ANNA JORDAN

Anna joined the team in spring 2024. She has worked as a production engineer in previous roles since 2017.

Civil Status: Anna lives with her husband and child in Västervik, and she also has two daughters who have moved out of the home.

Hobbies: She loves design, home styling and furniture making.

Fun Fact: Anna moved away at the age of 19 to work as an au pair and lived abroad for twenty years. She met her husband – a paratrooper in the British army – while travelling, and has lived in 16 cities across four countries.

ALEN MUMINOVIC

Alen joined the team in 2002 and started off working on the manufacture of temperature sensors and thermocouples. He became a production engineer in 2018.

Civil Status: Alen lives with his wife and daughter in Västervik, and he also has two adult daughters who have already moved out.

Hobbies: Trains at the gym six times a week.

Fun Fact: The Wellness Group at Pentronic draws on Alen's expertise to organise and run group-training sessions.

Biochar furnaces made in Sweden

– a climate-smart innovation from Hällekis

In Hällekis, at the foot of the Kinnekulle Ridge in Götene Municipality, Sweden, Edvard Hamilton has developed a climate-smart technology with enormous potential for the future. Here, his company manufactures biochar furnace which produce biochar, a material used to bind carbon dioxide and generate valuable heat.

BEHIND THE INITIATIVE is farmer and entrepreneur Edvard Hamilton who runs Hjelmsäters Estate, an historic estate that dates back to the 18th century.

"In my opinion, it's important that we take responsibility for the future and for the next generation," says Edvard, who is the CEO and Owner of the company Brachio AB which has been producing Swedish-made biochar furnaces in Hällekis since 2019.

"One of the main climate benefits of biochar – which is a highly stable, solid form of the element carbon – is its ability to sequester carbon dioxide in the soil long term," explains Edvard.

Recognised the huge potential of biochar

Hjelmsäters Estate has grown cereals for centuries, although its thin, nutrient-poor soil is not exactly optimal for producing crops. Climate change and dry summers have also had an impact on harvests. When Edvard began exploring ways to improve the soil quality, he recognised the potential of biochar as a soil conditioner.

"Thanks to its porous structure, biochar can retain water and nutrients. At the same time, it also contributes to the stimulation of microbial activity in the soil, producing good conditions for plant growth.

Edvard then quickly realised an other, even greater, potential for biochar.

"I wanted to do more than just get the most out of the land," he says.

Edvard contacted a company that had made attempts to produce biochar, but he was surprised by the answer he received.

"Do it yourself," they said. They were not able to supply the biochar that they had produced themselves.

So together with Björn, the blacksmith who runs the business at Hällekis, Edvard went on a study visit to Germany where he found a producer.

"We realised immediately that we could produce better furnaces ourselves, and that we could offer quality, Swedish-made biochar furnaces. Since then, we have developed the most efficient and reliable biochar furnace on the market," says Edvard.

The process also produces valuable heat

In 2016, with the help of the Swedish Environmental Protection Agency's investment support programme, Klimatklivet, he invested in Sweden's first modern biochar plant for agricultural use. A pyrolysis furnace was installed to produce 700 cubic metres of biochar per year while simultaneously generating 160 kilowatts of heat. The raw material used in the process is wood chips.

"The surplus energy is used to heat the estate's residential buildings, utility buildings and workshops, and in heating water and drying grain," explains Edvard.

The initiative immediately attracted plenty of attention when the modern biochar plant was operationalised in February 2018. Its success led to an increase in the production of biochar furnaces in Hällekis where the business now manufactures three different models, from 160 to 400 kilowatts, adapted for all purposes, from agriculture to industry. The annual production from Swedish biochar furnace is now as high as 22,000 cubic metres of biochar, which is equivalent to around 15,000 tonnes of sequestered carbon dioxide per year.

Strict Requirements for Accurate **Temperature Measurements**

The pyrolysis process used in biochar furnaces to produce biochar requires precise temperature controls.

"The thermocouples and temperature sensors we use from Pentronic are important in allowing us to optimise our process and ensure exact temperatures in our furnaces," say Edvard Hamilton and Rickard Olsson from the company Brachio AB.

PYROLYSIS IS a process whereby biomass or biowaste is heated in an oxygen-free environment, causing the material to break down without being incinerated, developing instead into biochar.

Products supplied by Pentronic play an important role in the process as the temperature needs to be around 800 °C.

"Temperature control is crucial when producing biochar as temperature affects both the quality and properties of the final material," explains Morgan Norring, Sales Engineer at Pentronic.

For a sustainable future

The collaboration began five years ago. "We contacted Pentronic as we wanted to use Swedish suppliers and Swedish components in the production of our biochar furnaces in Hällekis, Sweden," explain Edvard Hamilton and Rickard Olsson.

Morgan Norring is pleased that Pentronic was entrusted to play a role in this environmental effort.

"It's always great to be able to contribute to green initiatives and support companies from the start, and hopefully we will get to continue alongside them on their journey towards a sustainable future," says Morgan.

Carbon sinks and carbon offsetting

Biochar is a climate-smart alternative with a variety of different applications. Biochar can improve cultivation conditions within agriculture, horticulture and urban farming. The surplus energy from the pyrolysis process in biochar furnaces also generates heat that can be used to heat buildings, industries and other facilities.

And because biochar stores carbon dioxide, it also functions as a carbon sink – a way of storing carbon in the ground for hundreds, possibly thousands, of years.

"One kilogram of biochar in the ground is equivalent to 3.6 kilos of carbon dioxide in the atmosphere," explains Rickard.

Edvard has also taken the initiative to sell carbon offset credits based on biochar – a method which contributes to reduced carbon emissions and sustainable development.

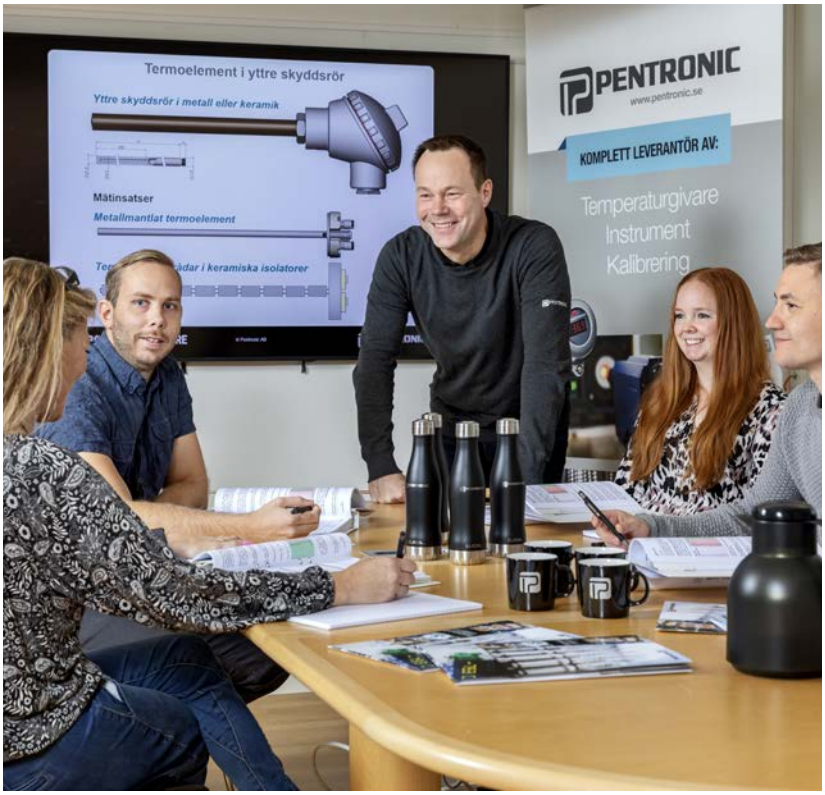
"There is huge interest among companies and other stakeholders. My farm has been on the list for sold carbon credits for four years and at the end of last year we were even in 48th place worldwide," Edvard notes.

Read more about biochar and biochar furnaces at: www.biokol.se

Pentronic supplies temperature sensors for biochar furnaces made in Hällekis – these furnaces are a particularly climate-smart solution as they both produce biochar and also generate heat that can be used to warm buildings.

Invest in **knowledge** about **traceable temperature measurement**

Training in temperature measurement can often be a more profitable investment than buying new measuring equipment. When it comes time to invest, you will then have the knowledge to make wise purchasing decisions. We can therefore promise that Pentronic's courses are a valuable investment.



EXTREMELY SMALL TEMPERATURE differences can have major consequences. We all know this, not least in the light of global warming.

Temperature in all industries is measured and regulated at a wide variety of points. This is done to save energy and resources and to give products the correct properties. The constantly increasing specialisation and optimisation of processes are also increasing the demands for extreme measurement accuracy. To guarantee precise measurement results, it is not enough just to install a high-quality sensor. All measurement also depends on being able to either exclude or evaluate a number of error sources in order to ensure highly accurate measurements. Pentronic's training courses are designed to give measurement technicians and engineers good knowledge about measurement uncertainty and traceability. We give course participants knowledge, tools, and practical experience so that they can evaluate a measurement chain comprised of several possible error sources.

Correct evaluations and traceable measurements create good conditions for high quality, fewer errors and reduced costs for your process.

PENTRONIC ACADEMY

Pentronic has been training measurement engineers since 1991 with our courses "Traceable temperature measurement 1" and "Traceable temperature measurement 2". The training is adapted and updated continuously to correspond current needs and knowledge requirements. AKL, our accredited calibration laboratory holds us updated with new methods and standards. Pentronic also offers training courses on site at customers. Our website www.pentronic.se provides extensive information and technical articles about temperature measurement and equipment.

ST1, Traceable temperature measurement 1

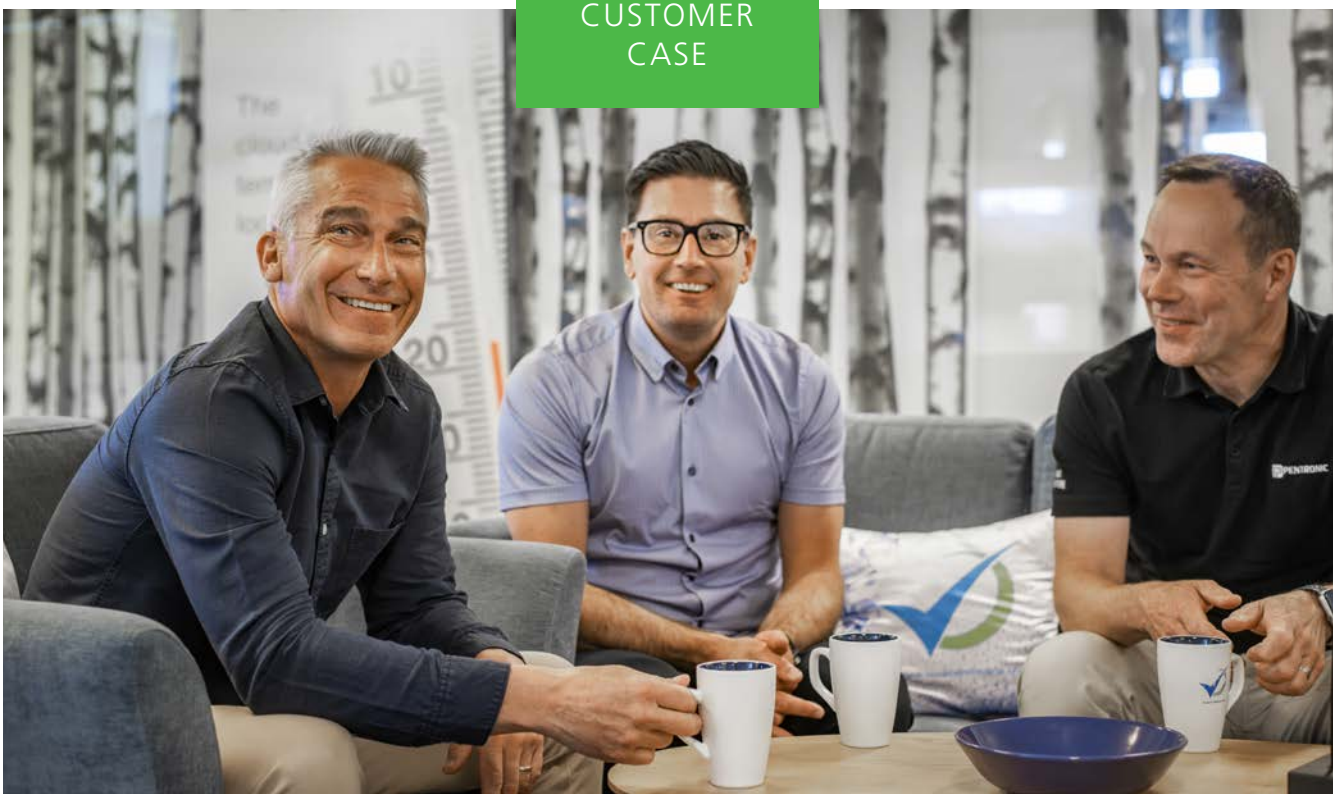
This course is for people who want basic training in traceable temperature measurement. No formal basic knowledge is necessary. The course begins with a review of various measurement methods, continues with practical laboratory exercises in calibration and sources of measurement error, and concludes with a summary in the form of an analysis of the measurement uncertainty. The course is held over two days. You have constant access to the instructors and the opportunity to discuss your own questions about measurement. After this course you will know where to find the problems and how accurately you are actually measuring.

ST2, Traceable temperature measurement 2

This course was created to handle the follow-up questions from the course ST1. ST2 is a more in-depth treatment of topics in the basic course with the emphasis on calibration and measurement uncertainty. "Traceable temperature measurement 2" is for people who have previously taken ST1 or have equivalent knowledge. It lasts for three days, one of which is dedicated to the accredited calibration laboratory. There will be time to discuss your measurement problems, either within the group or individually with the instructors.

On-site training

Pentronic has extensive experience of providing training at customers' premises in various forms, for both small and large groups. We can present either our regular training or a customised version based on ST1. An on-site course at your company will lead to new insights and knowledge that can be directly applied in your own business.



Per Hammargren (ICU), shown here with Christophe Zaninotti and Lars Grönlund (both Pentronic), considers Pentronic's working methods and production setup a key component of the collaboration.

Securing Critical Environments Via High Measurement Accuracy

ICU Scandinavia AB develops and markets quality assurance systems for use in laboratories, cold storage facilities and food safety. Measurement accuracy and high levels of traceability are central to the company's tailored solutions.

"Temperature measurement is one of our most important parameters and it constitutes a crucial part of what our log systems monitor," says Per Hammargren, Product Manager and founder of the company.

Per Hammargren.

THE COMPANY'S QUALITY assurance systems boast high levels of traceability and are used to monitor a range of parameters in critical environments.

"Our solutions are built up from systems and applications that are adapted to our customers' needs and businesses," explains Per.

The company's customers include hospitals, laboratories, blood centres, research environments and pharmaceutical companies. These enterprises often have a need to ensure the correct temperatures in fridges and freezers where materials such as biological samples, vaccines and blood plasma are stored.

"Our quality assurance and cleanroom logging systems measure temperature, air humidity, carbon dioxide, pressure, particle levels in the air and a range of additional parameters," explains Per.

A multi-year collaboration with Pentronic

ICU's quality assurance systems include Boomerang, which is designed primarily for different types of laboratories, and CoolGuard, which is a temperature monitoring system used in various kitchen environments. Both systems have built-in security features and store all measurement data to ensure full traceability.

"The software is developed in line with customer requirements and even hardware, such as sensors and other devices, can be adapted to the individual business. As our customers have

Pt100 sensors in these cryogenic liquid-nitrogen tanks – as used at IVF clinics and shown here – keep the temperature at –196 °C. If it rises, the ICU "Boomerang" system sounds an alarm to prompt nitrogen refill.

"Our systems are cloud based, meaning we can offer our solutions all over the globe."

Sten Drakenberg.

high expectations around measurement accuracy, it is reassuring for us to have Pentronic as a partner," says Per.

Pentronic has supplied several different sensor types for use in ICU's systems over the years.

"We build and calibrate temperature sensors on the basis of specific needs," explains Lars Grönlund, Sales Engineer and Technical Expert at Pentronic.

"Our collaboration with ICU is constantly evolving. It puts our skills to the test, requires us to be flexible and pushes us to always adapt our solutions," continues Christophe Zaninotti, Sales Engineer at Pentronic.

High demands on measurement accuracy

Ever since it was founded in 1992, ICU has placed its focus on tailored solutions, and it first commenced its collaboration with Pentronic almost twenty years ago.

"We delivered our first quality assurance system in 1998. Back then, we built the temperature sensors ourselves in our lab, but we were quick to realise the value of a partnership with Pentronic," explains Per.

Initially, ICU used digital sensors in simpler freezers that could go down to temperatures of -18°C.

"When we started working with ultra-low temperature freezers, which can maintain lower temperatures of -40 to -196°C, we encountered a need for more advanced equipment and greater levels of measurement accuracy. The solution was to use Pt100 sensors from Pentronic," says Per.

Lars Grönlund adds:

"We developed sensors that were adapted to ICU's systems and we also manufactured digital temperature sensors tailored to their needs."

Training and calibration

Per Hammargren highlights Pentronic's working procedures and production set-up as important elements of their collaboration.

"It's valuable for us to be able to discuss ideas and solutions with Lars and Christophe, who are both experts in what they do."

ICU updates its software several times per year in line with customer needs, and this makes it necessary to work with a flexible supplier.

"Pentronic has the speed and the expertise we need to quickly adapt a product as required," says Sten Drakenberg, CEO of ICU Scandinavia.

The company also uses Pentronic regularly for training within measurement technology and equipment calibration.

High standards extend even to IT security

ICU is in the midst of an expansion phase and growing into new markets.

"We are seeing a sharp increase in demand from new areas with high requirements for measurement accuracy and several measurement points in their processes. Some examples include the pharmacy sector, the pharmaceutical manufacturing sector, food production and other enterprises that work with cold storage and logistics.

"Our systems are cloud based, meaning we can offer our solutions all over the globe. Plus, in addition to ISO 9001 and 14001, we also hold ISO 27001 certification, allowing us to meet all of the stringent requirements that government authorities and other customers place on IT security," concludes Sten Drakenberg. ▮

ICU SCANDINAVIA AB

ICU was founded in 1992 by Per Hammargren and others. It develops and markets quality assurance systems for use in laboratories, cold storage facilities and food safety. The company operates globally and has customers and partners in around 25 countries. Their head office is located in Täby and their development unit is based in Båstad.

A Hugely Experienced Team!

The team in our mechanical workshop plays a key role within Pentronic's manufacturing process – working at high degrees of precision, they produce thousands of different parts for temperature sensors and measuring equipment.

"We produce up to 4,000 different articles," explains Production Leader Matts Pettersson.

Matts Pettersson.

TO KEEP AHEAD of the curve and work smarter, it is important that we always keep up with technological developments. For this reason, our machinery is constantly being updated.

Earlier this year, we commissioned a new CNC machine which has boosted our capacity. At the same time, the skills and experience of our employees provide us with a great deal of flexibility and a good ability to produce tailored solutions.

"The challenge is that we manufacture so many different products that are subject to strict requirements for precision, tolerance and surface finish," says CNC Operator Kristoffer Ekström.

"I feel confident to be working with this team that possesses such a huge amount of collective knowledge. What's more, sick leave rate is low and we can cover for each other when needed," says Matts Pettersson.

Experience is essential

Parts are machined in the workshop using eleven CNC machines. Employees work in two shifts with three operators on each team.

"We work with stainless steel of different grades and various high-temp materials. Because we often do small batches, there are lots of set-ups that have to be made, and a great deal of programming is required," says Markus Rosén.

"Some of our products are built to protect sensors and temperature gauges. It is therefore essential that they can withstand tough environments and demanding production processes," says Jonas Waldenstål.

"Deep-hole drilling is a particular challenge – drilling straight with a high degree of precision down to 500–600 millimeters requires both experience and a high degree of alertness and attentiveness during the process," continues Henric Pettersson.

"There are still a lot of steps that need to be done manually," adds Lotta Karlsson.

Accuracy and self-motivation

Machining thousands of different articles with diameters of 3–65mm requires both great accuracy and a lot of training. Johan Hjelm, who was hired in 2024, has quickly slotted into the team.

"I've been given great training and support, although you also need self-motivation and a willingness to learn. Joining the team has been really nice and seamless," says Johan.

When Lotta first started seven years ago, she already had ample experience with machining, but she had not previously worked with CNC machines.

"It was a challenge to learn everything, but once I got the hang of it and figured out what I needed to do, I quickly got into the swing of things," she explains.

Even the most experienced on the team are constantly learning.

"It's a continuous learning process. We work in a very broad field and problem-solving is an important part of what we do," says Lars Gutlöv, who has been a CNC Operator for 25 years.

Jonas Waldenstål has worked in the mechanical workshop for even longer than that.

"As our parts become more advanced and the machines continue to develop, there is a constant need to learn new things," says Jonas, who is also studying manufacturing technology through the higher vocational education programme at Campus Västervik and Nova in Oskarshamn.

A well-bonded team

Employees appreciate both the variation in their work as well as the atmosphere at the workplace.

"We programme, reset and operate machines, and this makes our work very varied," says Lars.

"At the same time, we also have a very good team spirit."

Pentronic attaches great importance to ensuring access to skills and talent in the long term.

"Part of this work involves taking on apprentices and retaining older machines for training purposes. This gives the trainees an opportunity to learn, and they can try out and operate CNC machines for themselves," says Lars.

Kim, who is currently a trainee in the mechanical workshop, is very happy with the set-up.

"It's been very educational and my colleagues are lovely," he says.

1. MARKUS ROSÉN
Joined in 2001 as a CNC Operator.
Civil Status: Lives with his wife and two children in Överum.
Hobbies: Likes riding his motorbike, exploring the archipelago by boat and spending time at home in the garden.

2. LOTTA KARLSSON
Joined in 2018 as a CNC Operator. Extensive previous experience with machining.
Civil Status: Lives with her husband in Västervik.
Hobbies: Likes being out on the water. She has her own boat and also enjoys walking in the woods.

3. KRISTOFFER EKSTRÖM
Joined in 2017 as a CNC Operator. Previous experience with CNC machining in the industry.
Civil Status: Lives with his wife and four children in Västervik.
Hobbies: Enjoys spending time with his family and playing frisbee golf.

4. HENRIC PETTERSSON
Joined in 2001 as a CNC Operator. Currently works with CAD/CAM and calibration.
Civil Status: Lives with his wife and three children in Ankarsrum.
Hobbies: Enjoys spending time with his children and being at home working on renovations. Also likes taking his boat out to fish on Långsjön Lake.

5. LARS GUTLÖV
Joined in 1999 as a CNC Operator.
Civil Status: Lives in an apartment in Västervik.
Hobbies: Enjoys going out on his mountain bike.

6. MATTS PETTERSSON
Joined in 1995 as a CNC Operator. Was previously a team lead and now works as a production manager.
Civil Status: Lives with his partner in Västervik.
Hobbies: Enjoys riding his motorbike, going out on the water and looking after the house.

7. JOHAN HJELM
Joined in 2024 as a CNC Operator. Moved from Fagersta where he had a similar job.
Civil Status: Lives with his girlfriend in an apartment in Gamleby.
Hobbies: Has three cats and three lizards as pets. Enjoys going to the gym, fishing and being outdoors.

8. JONAS WALDENSTÅL
Joined in 1995 as a CNC Operator.
Civil Status: Lives with two children in Västervik.
Hobbies: Enjoys spending time doing activities with his kids and riding his mountain bike. He is going to try cross-country skiing, which is one of his son's interests, and he likes being at home and in the garden.

9. KIM BERGSTRÖM
Currently completing an internship (APL) and studying the industry course at an adult education centre. Plans to train as a CNC Operator.
Civil Status: Lives in an apartment in Västervik.
Hobbies: Fishing and computer games.

TECHNICAL ARTICLE

Ramp Behavior in Temperature Measurement

Intended vs. Actual Measurement

Unfortunately, it's not always possible to determine the temperature that you actually want to measure. Figure 1 gives an example of a measurement installation, where the sensor consists of an encapsulated thermocouple in an immersion pocket. The sensor could also be a Pt 100 sensor. We want to determine the temperature of the air that flows through the pipe. The air temperature in the pipe may vary over time, but the air velocity is constant. In the case that we will look at below, the air temperature in the pipe is significantly higher than the temperature in the pipe›s surroundings.

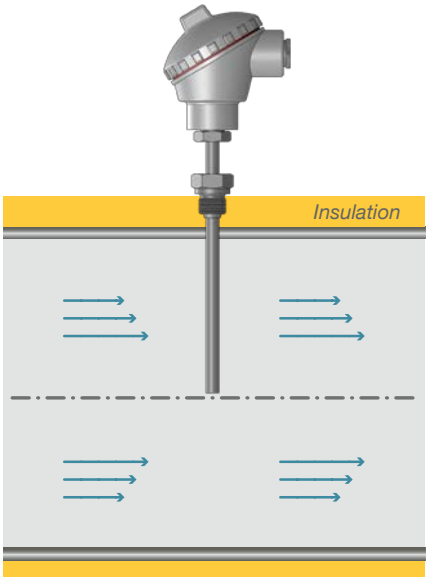


Figure 1: Instrumentation Setup.

The temperature we want to measure is constant

We want to consider the case where the air temperature in the pipe is constant, and we begin by studying the heat flow. Heat is transferred from the air in the pipe to the immersion pocket by forced convection. In the immersion pocket and the sensor, heat is transported through thermal conduction. Where the immersion pocket is attached to the pipe, heat is exchanged with the pipe wall through thermal conduction. A certain amount of heat exchange through thermal conduction can also occur with the pipe's insulation. Outside the insulation, heat is transported from the coupling head to the surroundings through convection and radiation. If the air velocity in the surroundings is negligible, the convective heat transport occurs through natural convection.

In this case, there is a small heat flow in the immersion pocket with the sensor, from the air in the pipe to the pipe's surroundings, the temperature of which is lower than the air temperature in the pipe. This means that the measuring point in the sensor will measure a temperature that is somewhat lower than the air temperature that we want to determine.

Thermocouple and Pt 100-type sensors are so-called contact sensors that measure their own temperature and absolutely nothing else. So in this case there is a difference between the temperature that we want to measure – the air temperature in the pipe – and the temperature that we actually measure – the temperature of the sensor. In some cases, the measurement error can be disregarded, but this must be decided on a case-by-case basis.

The temperature we want to measure varies with time

In the measurement installation shown in *Figure 1*, we now assume that the air temperature in the pipe varies with time. This almost always means that the response time to a temperature change in the pipe is of interest. When discussing response time, we often assume that the temperature we want to measure changes in the form of a step between two temperature levels. Unfortunately, these types of temperature changes rarely occur in engineering applications. What usually happens is that the temperature change between two levels takes the form of a ramp. We will therefore take a closer look at this case.

We now take the measurement installation in *Figure 1* as a basis and make the following assumptions. The inner diameter of the pipe is 200 mm, the outer diameter of the immersion pocket is 10 mm, and its length inside the pipe is 100 mm. Air flows in the pipe and the air temperature changes slowly at regular intervals between two levels, 30 °C and 180 °C. Each change takes approximately 20 minutes. We also assume that the heat flow from the immersion pocket with the sensor to the surroundings is negligible.

Figure 2 shows a basic picture of the temperature in the pipe and the measured

temperature as a function of time. When the air temperature changes in the pipe, the sensor in the immersion pocket measures the air temperature with a certain lag. After some time, the temperature deviation becomes constant. Since, in this case, the heat flow from the immersion pocket to the pipe's surroundings is negligible, the measured temperature will connect with the constant upper temperature level after a certain length of time. The difference between the air temperature in the pipe and the measured temperature can be regarded as a measurement error. The time-dependent measurement error in this case depends, among other things, on the appearance of the ramp, the geometry and physical properties of the immersion pocket and sensor, and the heat transfer coefficient between the air in the pipe and the immersion pocket.

In some cases, we have a heat flow from the air in the pipe to the surroundings via the immersion pocket and the sensor. The measured temperature will then connect to a slightly lower temperature than the constant upper temperature level in the ramp.

To determine the difference between the temperature we want to measure and the temperature we actually measure, we can calculate the temperature distribution in the immersion pocket and the sensor. This is a three-dimensional time-dependent heat conduction problem. For the temperature, T, in °C in the immersion pocket with the sensor, $T = T(t, x, y, z)$, where t is the time in seconds, and x, y and z are Cartesian coordinates in metres.

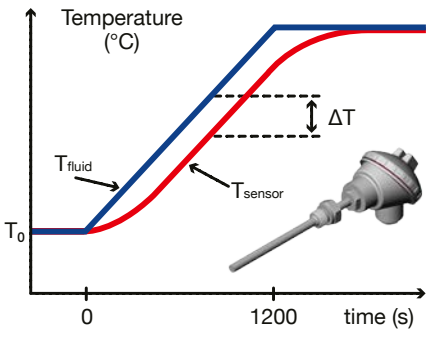


Figure 2: Temperatures as a function of time.

To calculate the temperature field, we must use the heat conduction equation with associated boundary conditions and initial condition. Unfortunately, there is no general analytical solution to this three-dimensional time-dependent problem, so we must use some suitable numerical method. In this case, it makes sense to use the Finite Element Method, FEM.

> "Unfortunately, it's not always possible to determine the temperature that you actually want to measure."

If we ignore the heat flow in the immersion pocket and sensor to the surroundings in the axial direction (z-direction), we can simplify the problem. This restriction means, among other things, that we disregard the heat exchange with the pipe wall, the pipe insulation and the pipe's surroundings. With this assumption, we need only study what happens in a cross section of the immersion pocket and the sensor, which makes the problem two-dimensional, $\boldsymbol{T = T(t, x, y)}$, where x and y are coordinates in the cross section. This problem is considerably simpler than the three-dimensional problem. Unfortunately, even in this case, a numerical method is almost always required to calculate the temperature field.

If the temperature difference within the cross-section of the immersion pocket and sensor were considerably smaller than the temperature difference between the surface of the immersion pocket and the flowing air in the pipe, the problem could be simplified further. If we disregard the temperature differences within the immersion pocket and sensor, the temperature would be $\boldsymbol{T = T(t)}$. This means that the temperature within the immersion pocket and the sensor only depends on time t.

To solve the simplified problem, the so-called "lumped-heat-capacity method" can be used in some cases, which gives us a first-order differential equation. In many technically important cases, there is also an analytical solution to this problem.

To determine whether the "lumped method" is applicable, we can use a dimensionless number, the so-called Biot number, $\boldsymbol{Bi = (hL)/k}$, where h is the heat transfer coefficient in $\boldsymbol{W/(m^2K)}$ between the immersion pocket and the flowing air in the pipe, L is a characteristic length in metres for the geometry in question, and k is the thermal conductivity in W/(m K) in the immersion pocket and the sensor. If the immersion pocket is regarded as a long cylinder with perpendicular flow, the characteristic length is L = D/4, where D is the diameter of the immersion pocket in metres.

The Biot number is basically a measure of the ratio between the temperature difference within the cross section and the temperature difference between the surface of the immersion pocket and the flowing air in the pipe. The "lumped method" can be used if the Biot number is small. In engineering applications, the method generally gives acceptable results if Bi < 0.1.

An example of temperature change in the form of a ramp

To determine the magnitude of the measurement error, the simplest possible method should be used. In this case, an engineering assessment needs to be made. We therefore start by checking whether the "lumped method" is applicable.

The outer diameter of the immersion pocket is 10 mm, which gives the characteristic length L = 0.0025 m. The heat transfer coefficient varies along and around the immersion pocket, and we use a mean value. With an air velocity of 10 m/s in the pipe, the heat transfer coefficient is approximately 95 W/(m²K), if we regard the diving pocket as a long cylinder with a perpendicular flow. The physical data of the air varies with the temperature, and we should therefore use a mean temperature, which in this case is (30 + 180)/2 = 105 °C. If we assume that the immersion pocket and sensor mainly consist of stainless steel, k = 15 W/(m K).

The Biot number with these values is 0.015, and the "lumped method" can be used, since Bi < 0.1.

Continue reading ➔

When using the "lumped method" to calculate the change in temperature over time, we must always bear in mind that the method is approximate, and that the calculation is based on a number of conditions and assumptions. It is therefore very important to remember this when evaluating the calculation results.

If we now assume that the "lumped method" applies, we are able, with the current assumptions, to determine the change in sensor temperature over time based on the following differential equation

$$\boldsymbol{dT/dt + ((4h)/(\rho cD))T = ((4h)/(\rho cD))T_{Fluid}}$$

where, ρ is the density of the immersion pocket in kg/m^3 and c its specific heat capacity in (Ws)/(kg K). Both the density and the specific heat capacity vary within the cross-section of the studied cylinder, which consists of the immersion pocket and the sensor. This means that we must use the mean values of both the density and the specific heat capacity.

The air temperature in the pipe in this case changes in the form of a ramp: $\boldsymbol{T_{Fluid} = T_0 + Bt}$ where, T_0 is the air temperature at time t = 0, and B is a coefficient that characterizes the appearance of the ramp and is given in °C/second. The initial condition required for the solution to the equation in this case is $T = T_0$, i.e. the cylinder temperature is equal to the air temperature at time t = 0. We now assume that the parameters h, ρ, c and B can be regarded as constants.

With the introduced conditions, the differential equation has the analytical solution

$$\boldsymbol{T = T(t) = T_0 + Bt - (\rho cDB)/(4h) + ((\rho cDB)/(4h))\, e^{-(4ht)/(\rho cD)}}$$

This solution applies as long as the air temperature in the pipe changes in the form of a ramp. In this case, the relationship applies during the time 0 < t < 1 200 seconds.

The first two terms in the equation solution are the temperature of the ramp, i.e. the temperature change of the air in the pipe. The last term in the equation solution represents the settling process, which starts at time t = 0. The term contains the expression $e^{-(4ht)/(\rho cD)}$, which decreases with time t. This means that the settling process will "die out" after some time – the settling time.

The penultimate term in the equation solution, (ρcDB)/(4h), is the constant deviation, ΔT °C, between the temperature of the air in the pipe and the measured temperature, which is obtained when the settling process has "died out"; $\boldsymbol{\Delta T = (\rho cDB)/(4h)}$. *See also Figure 2.*

Based on the expression for ΔT, which represents the difference between the air temperature in the pipe and the temperature we measure, we can make a number of interesting observations. For the measurement error ΔT the following applies: $\boldsymbol{\Delta T = (\rho cDB)/(4h)}$

If the air velocity in the pipe were to increase, the heat transfer coefficient h W/(m^{2}K) will increase, and this means that the deviation ΔT will decrease. We also find that the faster the air temperature in the pipe changes (larger B), the greater the deviation ΔT.

The deviation ΔT also increases with the outer diameter D of the immersion pocket, but here the relationship becomes a little more complicated, since an increase in the diameter D also affects the value of the heat transfer coefficient h W/(m^{2}K). If the diameter of the immersion pocket were to increase from 10 mm to 12 mm, the heat transfer coefficient h W/(m^{2}K) would decrease by approximately 7%. Overall, this means that the deviation ΔT increases by almost 22% when the outer diameter increases by 20%.

For the current case, **B = (180 – 30)/1200 = 0.125 °C/s** applies, and for the cylinder we use values for stainless steel; ρ = 7900 kg/m^3 and c = 480 (Ws)/(kg K). With these values, we get ΔT = 13 °C. The settling process takes just over 7 minutes. It should be pointed out once again that the calculation method is approximate and based on a number of assumptions and conditions. Nevertheless, the result gives a good idea of the measurement method and its limitations, as well as the parameters that affect the deviation ΔT. We could put it as follows: "The calculation is not perfect, but it is good enough in an engineering context."

If a more accurate calculation is required, it will be necessary to study the two or three-dimensional time-dependent problem, and use an appropriate numerical method.

Some comments on the calculation results regarding the ramp measurement

The maximum deviation between the air temperature we want to measure and the sensor temperature we measure is in this case approximately 13 °C. This value is almost 9% of the difference between the two temperature levels 30 °C and 180 °C. If the primary interest in the temperature measurement concerns the two temperature levels in the ramp, we could, perhaps, accept the deviation ΔT = 13 °C, which only affects the part of the process where the temperature changes between the two levels. However, if you want to have control over the entire temperature process, a deviation of 13 °C is barely acceptable.

To reduce the measurement error that always arises when this type of equipment is used for measuring, you could, for example, use an immersion pocket with associated sensors that have a smaller outer diameter. If the outer diameter of the immersion pocket is 6 mm, the heat transfer coefficient will be approximately 120 W/(m^{2}K), and the Biot number 0.012. We can therefore use the "lumped method". In this case, we get the deviation ΔT = 6 °C, which is approximately half the measurement error when the outer diameter of the immersion pocket was 10 mm. The settling time will also be about half as long.

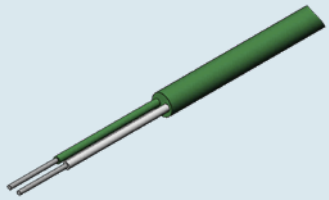
You could also install a sensor that is specially designed to provide as little deviation as possible between fluid temperature and sensor temperature during dynamic processes. *See example in Figure 3.*

Figure 3: Example of a Pt100 sensor with reduced tip, model 7945000.

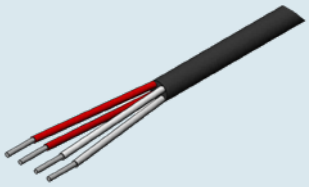
Dan Loyd,
Professor emeritus,
Linköping University
dan.loyd@liu.se

Common connection options for **thermocouples** and **resistance thermometers**

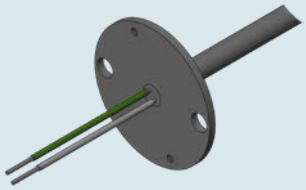
Connections are a critical part of your measurement chain and when choosing which one to use, it is important to consider not only the measurement uncertainty but also the accessibility, the surrounding environment and the ease of replacement. There is now a great variety of both connectors and casings, and in addition to choosing the type of connection it is also possible to choose between different versions of integrated signal converters. Various versions are available with 4 to 20mA or digital signal output.



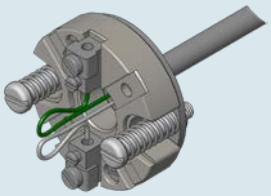
Thermocouple cable with free wires



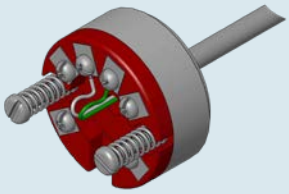
Pt100 cable with free wires



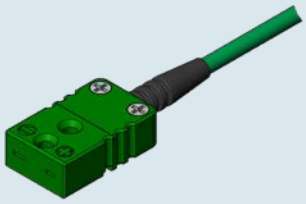
Measurement insert ready for mounting of a terminal head or transmitter (T/E or Pt100)



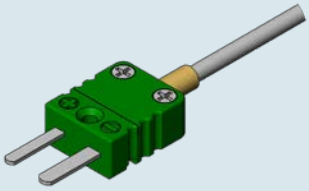
Measurement insert with terminal head (T/E or Pt100)



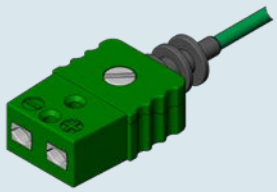
Measurement insert with transmitter (T/E or Pt100)



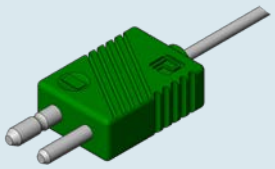
Miniature female connector mounted on a cable



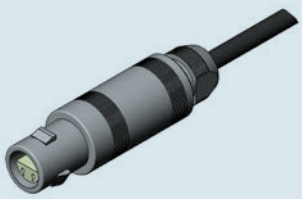
Miniature male connector mounted on a sheath



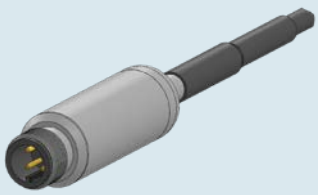
Standard female connector mounted on a cable



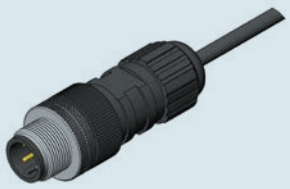
Standard male connector mounted on a sheath



LEMO connector mounted on a cable

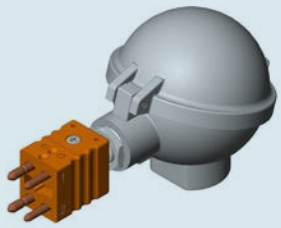


M12 connector with integrated electronics

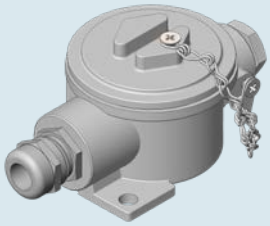


M12 connector mounted on a cable or sensor

M12 connector mounted on a terminal head



Thermocouple connector mounted on a terminal head



Terminal box for terminal block or transmitter

Overview and benefits of **Ethernet-APL**

Interoperability and flexibility
Ethernet-APL offers seamless connection of field devices (sensors, actuators, etc.) with fast and reliable data transfer rate. Thanks to its scalability, it can be used in smaller networks for short distances, as well as larger networks covering long distances, without the need to replace infrastructure.

Level in the network
Ethernet-APL is mainly used at field level (closest to the process). Here, it often connects directly to field devices in hazardous environments (Ex-zone 0, 1 and 2). To reach higher-level systems (such as PLC or SCADA), the APL network is usually connected via a gateway or switch.

Simplified installation
The use of plug-in connectors and the possibility of different network topologies (star, line, etc.) simplify installation. This makes it easier to both expand and maintain the system.

Improved communication
With a two-wire fieldbus cable, Ethernet-APL can handle robust and stable data communication in real time. This is particularly important in the process industry, where reliability and fast feedback are crucial to avoid disruptions.

Remote access and fast data transfer
The possibility of carrying out both configuration and troubleshooting remotely helps to increase efficiency and lower operating costs. The fast data transfer rate also makes real-time diagnostics possible, speeding up system commissioning and facilitating troubleshooting.

Built-in and intrinsic safety (Ex-zone 0, 1 and 2)
Ethernet-APL supports intrinsic safety in hazardous environments (Ex-classified zones). The low-energy use of the cable allows the protocol to be used in environments where there is a risk of gas and dust emissions, without compromising on communication performance.

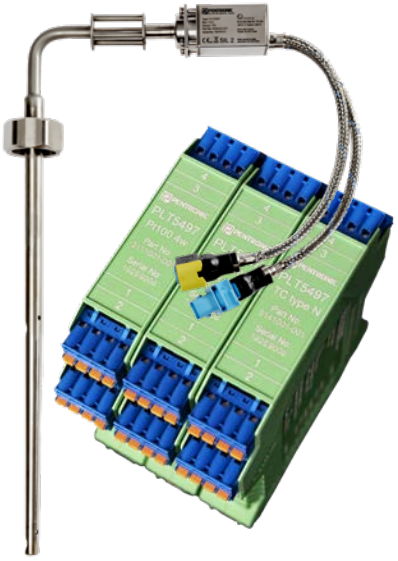
Power and data over the same cable
One of the major benefits is that both data communication and power supply are handled via the same wire pair. This reduces the need for separate power cables, which not only simplifies installation and cabling but also helps to reduce the overall equipment cost.

Summary
Ethernet-APL is a breakthrough technology for the process industry as it combines a standardized and reliable Ethernet protocol with a physically customized cable specification that makes intrinsic safety and long reach possible. Whether you are at field level (directly in the process) or need to communicate with PLCs and higher-level systems, Ethernet-APL offers a flexible framework for data communication and power supply. It also creates a robust foundation for future digitization initiatives within the industry.

ethernet-apl™
advanced physical layer

The Pentronic PLB5000 system

– A digital temperature measuring system for demanding environments



- Cost-effective, compact and robust measurement system
- Up to 120 measuring positions with high accuracy via digital bus
- Simple installation with minimal cabling
- Safety integrity level: SIL 2 IEC61508
- Intrinsic safety systems IECEx and ATEX
- Integrated signal converter for 1, 2 or 3 sensors, or DIN rail-mounted model for up to 4 sensors
- Inputs for Pt100/1000 or thermocouple Type K, N, R, S
- Gateway with PROFIBUS DP/PROFIsafe connection
  Gateway for IECEx/ATEX Zone 1 with PROFINET over APL connection will be launched in 2026
- High availability through redundancy

The PLB5000 system is designed for accurate temperature measurement in demanding environments. The system provides superior measurement and stability in small and robust casings. The signal converter delivers digital measurements, has a uniquely low power consumption and is easy to install with a minimum of cabling. Designed for applications where a high degree of flexibility, accuracy and safety is required.

Pentronic's partners instrument range (selection)

For more information, visit our website www.pentronic.se or contact one of our sales representatives.

Temperature indicators

Flow meters

Glass flow meters (GFM)

Moisture meters and NIR equipment

Transmitters

Calibration equipment

Fibre optics

Data loggers

Contactless IR pyrometers

Mechanical design simplifies and **solves problems**

Pentronic is well known for its expertise in temperature and measurement technology – where a large mechanical construction department and modern CNC-controlled machines for processing steel and other materials are also of great importance.

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THIS ENABLES THE design and manufacture of customized solutions for a variety of technical challenges, especially in areas such as the fixing and positioning of temperature sensors in existing process plants. Many installations are aged but still in good working order, even if sensors need to be replaced or calibrated. In these cases, there are good opportunities to implement more modern and cost-effective solutions than what was available at the time of the original installation. There is also a growing need for more measuring points in today's process systems, often in hard-to-reach or enclosed places.

Retrofit solutions for thermowells

When installed in existing thermowells, threaded connections can pose problems, in terms of both time and maintenance. Threaded solutions make sensor replacements difficult, especially in environments where corrosion and contamination affect thread function.

"Pentronic offers advice and system solutions to ensure reliable, accurate and cost-effective measuring points in both new and existing plants."

To simplify replacement, reduce installation space and optimize the cost structure, Pentronic offers customized adapters. These can be threaded into existing thermowells or permanently welded. The adapters are especially suitable for spring-loaded bayonet connections, allowing for quick and safe assembly and disassembly. The spring load ensures correct sensor placement against the bottom of the thermowell, improving both measurement accuracy and response time in the process.

Assembly optimization for superior measurement performance

Pentronic's sensors are of a high level of quality, and in most cases are supplied pre-assembled in protective tubes, which are adapted for direct installation in the customers' process systems. This ensures optimal measurement performance and process reliability.

Customized products are often complicated and costly to manufacture. Pentronic rises to this challenge by also providing a range of pipe adapters in varying dimensions. These enable quick and flexible installation of standard sensors, without compromising on measurement accuracy. Pentronic also has short delivery times for both standard and customized solutions.

The right coupling head for the right application

In the process industry, robust coupling heads are used for temperature sensors, mainly to protect a transmitter or facilitate cable connection to control systems and transmitters.

In applications where the transmitter is centrally located or where the sensor is intended for direct cabling, the coupling head can produce an unnecessary load. An unnecessarily heavy and unbalanced sensor design increases the risk of mechanical impact and vibration damage. Instead you can use a temperature sensor with cable or connector, such as M12 connector, which reduces physical size and cost while simplifying installation and reducing maintenance time.

Pentronic offers advice and system solutions to ensure reliable, accurate and cost-effective measuring points in both new and existing plants – contact us for more information!

Advice for handling temperature sensors

There are basically two different types of temperature sensor – resistance thermometers (often called Pt100 or Pt1000) and thermocouples.

Resistance thermometers (Pt100/Pt1000):

- Do not exceed the resistance thermometer's measurement range
- High temperatures together with thin sensors can shorten service life
- Do not expose the sensors to sudden impacts or vibrations
- Avoid thermal shocks
- Do not bend sensors made of sheath material (MI cable) too tightly. Minimum bending radius equals twice the diameter
- Tube/pipe sensors must not be bent at all
- The measurement environment can shorten service life. You should therefore regularly check the sensor's mechanisms and output signal

Functional testing of resistance thermometers (Pt100/Pt1000):

If the sensor has been exposed to mechanical shock or been bent, you should perform the following tests to determine whether it has been damaged:

- Measure the resistance between red and white, or yellow and blue, with e.g. a multimeter. At room temperature (23°C ± 4°C), the resistance should be between 106 Ω and 111 Ω.
- Using an insulation tester, measure the insulation between the inner conductor and the outer sheath. (see the extract from IEC 60751:2022 below).

Test voltage (Vdc)	Min. approved insulation (MΩ)
100	100

- Low insulation resistance is an indicator that the sensor should be replaced.

Thermocouples:

- Do not exceed the thermocouples measurement range.
- High temperatures together with thin sensors can shorten service life.
- Avoid thermal shocks.
- Do not bend sensors made of sheath material (MI cable) too tightly. Minimum bending radius equals twice the diameter.
- The measurement environment can shorten service life. You should therefore regularly check the sensor's mechanisms and output signal.

Functional testing of thermocouples:

If the sensor has been exposed to mechanical shock or been bent, you should perform the following tests to determine whether it has been damaged:

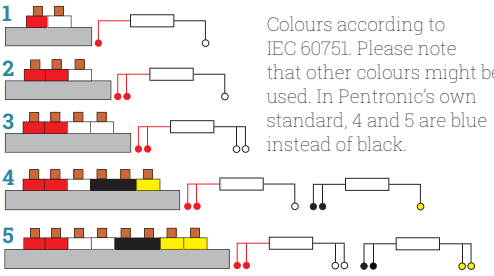
- With a multimeter, measure the resistance between the conductors.
- The resistance on a healthy sensor should be 0 Ω.
- An open input indicates a broken circuit.
- Using an insulation tester, measure the insulation between the inner conductor and the outer sheath (see the extract from IEC 61515:2016 below).

Outer diameter D (mm)	Test voltage (Vdc)	Min. approved insulation (MΩ)
0,5 < D ≤ 1,6	100	20
1,6 < D	50 till 100	1000

- Low insulation resistance is an indicator that the sensor should be replaced.

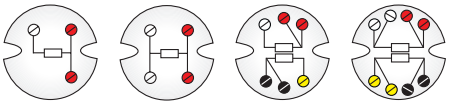
Contact us if you are unsure about the operation of your temperature sensor. Want to know more about temperature sensors? Visit www.pentronic.se
Download your test certificate at www.pentronic.se

Extension cable for Pt100s



Colours according to IEC 60751. Please note that other colours might be used. In Pentronic's own standard, 4 and 5 are blue instead of black.

Terminal block connector for Pt100s



Note that other colours may be used.

Max. recommended working temperatures for thermocouples with sheath material Iconel 600 (EN 2.4816), type K and N according to IEC 61515:2016

Ø mm	K and N
1 and less	700 °C
1,5	920 °C
2	920 °C
3	1070 °C
4,5	1150 °C
6 and more	1150 °C

Pentronic also manufactures sensors in specialised sheath alloys for thermocouples, designed for working temperatures up to 1250 °C (e.g. Nicrobel).

With regard to ceramic protection tubes: the Al03 tubes C799 and C610 are kept in stock. Recommended for thermocouples and working temperatures up to 1700 °C.

Other options for special applications are available on request.

Types of thermocouples

Type	IEC Color	Ansi MC 96.1 Color	Working-range in °C	Atmosphere
E			-200 - 900	Good in oxidising environments
J			-200 - 760	Not good in oxidising environments or acids
K			-200 - 1200	Good in oxidising environments
N			-200 - 1200	Like K but standardised to be better over 200 °C
T			-200 - 370	Not in oxidising environments
B			0 - 1700	Ceramic protection tubes, all environments
S/R			0 - 1480	Ceramic protection tubes, all environments
C/D			0 - 2315	Vacuum, not for oxidising environments
A			0 - 2500	Vacuum, not for oxidising environments

Properties of cable insulation materials

Type of material	T min	T max	Ex. of thermocouples	Ex. of resistance-thermometers	Abrasion resistance	Chemical resistance	Moisture resistance	Solvent resistance	Fire test
PVC	-15	105	8105000	7914000	4	4	3	2	4
PUR	-50	150	NA	7400000	4	3	3	3	3
NYLON	-65	121	6101000	NA	5	5	2	3	1
FEP	-65	200	8105000	NA	5	5	5	5	5
SILIKON	-100	200	6102000	7912000	3	3	4	2	5
PFA	-65	260	6101000	7300000	5	5	5	5	5
PTFE	-265	260	6101000	7300000	4	5	5	5	5
POLYIMID	-265	260	6101000	NA	5	5	5	4	4
GLASFIBER	NA	510	6102000	NA	1	3	3	5	5
KERAMISK FIBER	NA	1200	6101000	NA	2	3	2	5	5

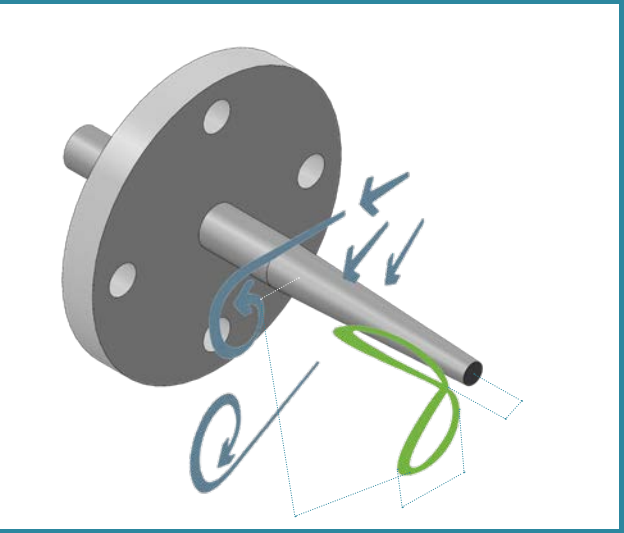
1-5 where 1 is worst and 5 is best. Note that the table describes generalised properties of the insulation material; the properties of specific cables may differ. When selecting a cable always consult the relevant data sheet for the precise specification.

Properties of **common materials**

We manufacture mechanical components, accessories, thermowells and tube necks from a variety of materials in our own precision tooling workshop. The table below lists a selection of our most common types of steel. We also do custom orders in titanium, copper, and a number of different plastics.

Type of material	Comment	EN 10027-2	EN 10027-1	AISI/SAE/ASTM	Other designation
Stainless steel	A highly versatile and common material suitable for moderate temperatures and environments.	1.4301 1.4307	X5CrNi 18-10 X2CrNi 18-9	304 304/304L	A2 stainless steel
Mo alloy stainless steel	The molybdenum alloy helps improve acid resistance suitable for the process industry. Also called acid-resistant steel.	1.4401 1.4436	X5CrNiMo 17-12-2 X3CrNiMo 17-13-3	316	A4 acid-resistant steel
Mo alloy stainless steel Low carbon content	Pentronic's standard material. The low carbon content helps improve properties in the the temperature range 425–925 °C where steel with a higher carbon content can exhibit problems with carbide precipitation/intergranular corrosion.	1.4404 1.4432 1.4435	X2CrNiMo 17-12-2 X2CrNiMo 17-12-3 X2CrNiMo 18-14-3	316L	
Mo alloy stainless steel titanium stablised	Excellent corrosion resistance.	1.4571	X6CrNiMoTi 17-12-2	316 Ti	Classic V4A
High temperature stainless steel	For temperature ranges up to 1150 °C. Excellent corrosion resistance. Abrasion resistant.	1.4749 1.4835 1.4854 1.4767	X18CrN28 X9CrNiSiNCe 21-11-2 X6NiCrSiNCe 35-25 CrAl 20 5	446 UNS S30815 UNS S35315	4C54 253MA 353MA Kanthal AF
Nickel-based alloys	Excellent corrosion properties, working temperatures up to 900 °C* Excellent properties in reducing environments.	2.4816 2.4819 2.4951/2.4630	NiCr15Fe NiMo16Cr15W NiCr20Ti	UNS N06600 UNS N10276	Inconel 600* Hastelloy C-276 Nimonic 75
Pressure vessel steel	Standardised material certified for use in industrial pressurised installations.	1.0460 1.5415 1.7335 1.7380	P250GH 16Mo3 / 15Mo3 13CrMo 4-5/13CrMo 4-4 10CrMo9-10	SA 105 A204 Gr.A A387 gr.12 A122 F22	C22.8

* Inconel 600 is designed for safe use over a very broad temperature range and is used as a sheath material in high quality sheathed thermocouples. Properly designed, an Inconel 600 sheathed thermocouple can withstand working temperatures up to 1150 °C. See further in the table below.



Wake frequency calculations

The American standard ASME PTC 19.3 TW (2016) describes a method for calculating Kármán vortex streets. These oscillations influence fixed thermowells in pipe flows. In flows, there is a risk that the wake effect will cause the thermowell to oscillate violently, with the result that it can break apart or break free from its mounting. The standard describes calculation models for various basic types of thermowell: these calculations are generally termed wake frequency calculations. For the analysis, the thermowell's dimensional, material and shape data are needed, plus data on the relevant environment, such as flow and pressure. The calculations show the thermowell's safe levels in relation to its natural frequency.

Pentronic offers wake frequency calculations as an additional service.

A properly designed thermowell

– is essential for both functionality and safety

The design of a thermowell is a central part in the configuration of any process – in terms of both performance and safety. It is essential that the thermowell complies with the requirements placed on it.

THERE ARE SEVERAL different standards that describe how thermowells should be designed and dimensioned. The most common is ASME PTC 19.3 TW-2016, however DIN 43772 is also often used. There are some differences between these two standards.

Calculation methods:

- ASME PTC 19.3 TW-2016 applies a more conservative calculation method for ensuring that thermowells will be able to withstand considerable strains, including both static and dynamic pressures.
- DIN 43772 focuses more on dimensional tolerances and material choice in order to ensure structural integrity under specific process conditions.

Vibration analysis:

- ASME PTC 19.3 TW-2016 contains detailed guidelines on how to address vibrations due to fluid flow, including both transverse and longitudinal vibrations.
- DIN 43772 includes less detailed requirements for vibration analysis and instead attaches greater importance to basic structural durability.

Materials:

- ASME PTC 19.3 TW-2016 specifies materials based on their ability to withstand high pressures and temperatures.
- DIN 43772 allows for greater flexibility in the choice of materials, placing focus instead on the need to meet specific process requirements.

Standardisation and application:

- ASME PTC 19.3 TW-2016 is more detailed and often used globally, especially within industrial operations such as the oil and gas industry.
- DIN 43772 is adapted to European standards and primarily used in industry in Europe.

As a general rule, the placement of the thermowell will determine which standard is used in connection with installation.

Sensor tips sometimes need protection from the process environment, both chemically and mechanically. Thermowells, also known as protection pockets, typically refer to fully machined straight or conical-bottomed pockets made of metal.

"The design of a thermowell is a central part in the configuration of any process – in terms of both performance and safety."

Model portfolio

A selection of Pentronic's portfolio is presented below. Please do not hesitate to contact us for more information or visit our webpage at www.pentronic.se

Mineral insulated thermocouples

Design: Large variety of designs, optional process connections and contacts.

Advantages: Very robust and versatile sensors with a wide area of application. Recommended for high temperature applications.

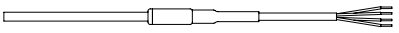
Model examples: 8102000, 8103000, 8105000, 11-00204.

Thread thermocouples

Design: Large variety of designs, optional process connections and contacts.

Advantages: Robust and flexible. Short respons time. Low cost.

Model examples: 6206000, 6101000, 6201000.

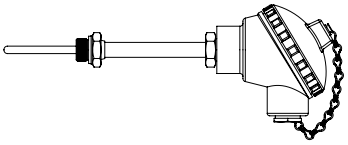


Resistance thermometers

Design: Large variety of designs, optional process connections and contacts.

Advantages: High accuracy, very versatile design options.

Model examples: 740000, 7917000, 7905100, 7913101.

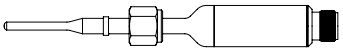


Process thermometers

Design: Large variety of designs. Available both as thermocouple or resistance thermometer. Several standardised process connections can be prepared. Connection head can be fitted with signal converter and several different contact options available.

Advantages: Proven and robust design. High degree of standarisation and interchangeability. Several designs have spare parts such as insertion probes and signal converters. Available in explosion-proof design.

Model examples: 8109600, 811000, 7941000, 7810900.

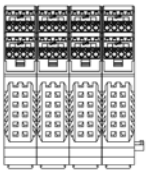


Integrated signal conversion

Design: Available as resistance or thermocouple thermometers. Multiple choice of digital communication protocol or 4...20mA signal available.

Advantages: Extremely good accuracy can be achieved. Minimal cabling and significantly simplified installation as well as service.

Model examples: PAT1101, PLT1101, PIO1101.



Measurement systems

Design: Complete measuring system for thermocouples and resistance thermometers as well as pressure. Signal conversion and low energy field bus protocol for demanding applications.

Advantages: Extremely good measurement accuracy. High safety level (SIL).

Model examples: PLB1000 and PLB5000.

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Glass flow meters
Ex/ATEX applications
Transmitters & system architecture
Contact-free measurement
Flow measurement

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Equipment for high temperature applications
Travelling loggers
Calibration & calibration equipment
Mechanical adaptation

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Calibration & calibration equipment
Hygienic applications
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Steel & metal industry
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Chemical industry

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Life Science/ pharmaceuticals
Vehicles & engines

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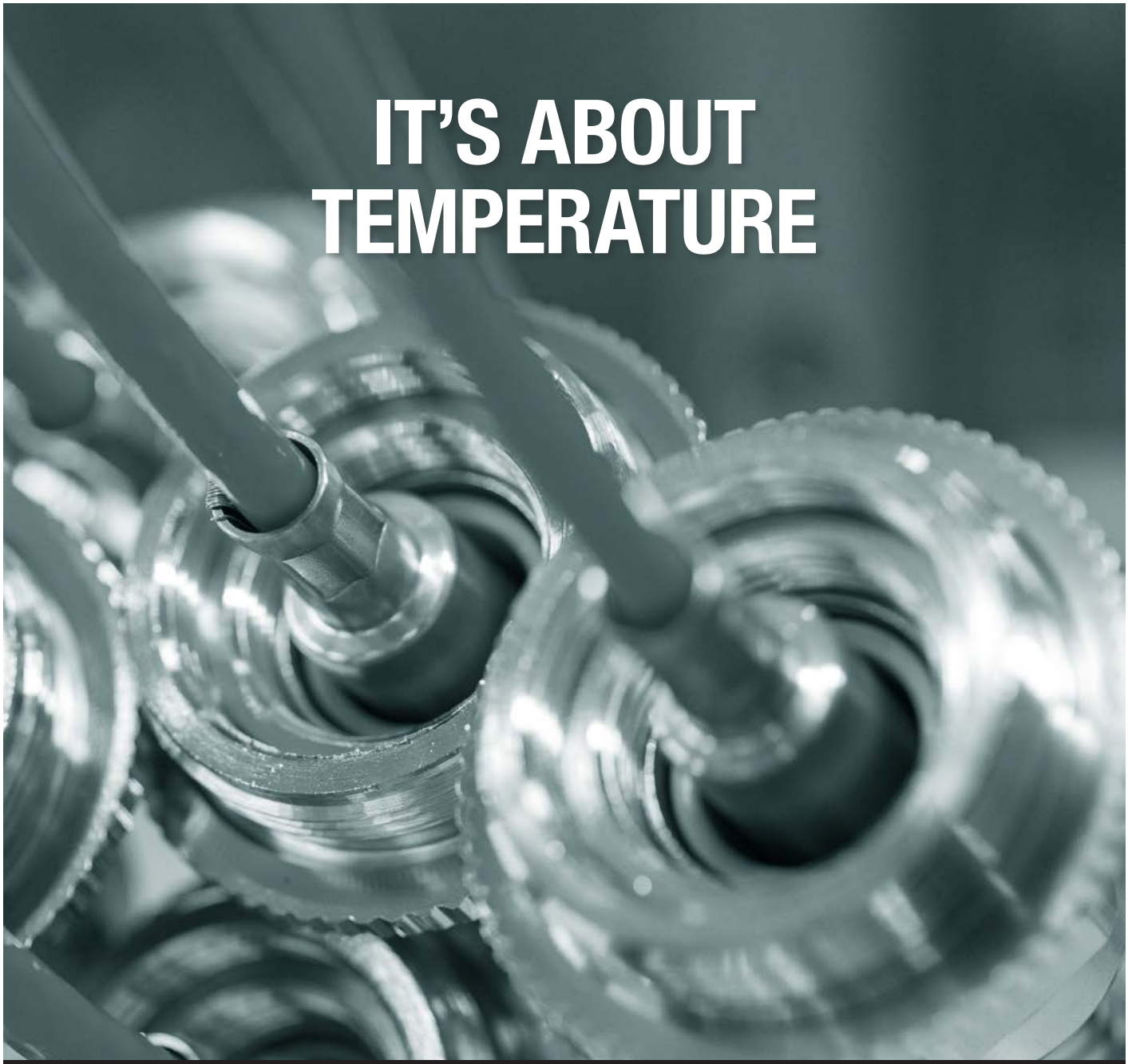

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