IT'S ABOUT TEMPERATURE

PENTRONIC

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Impressive symbol of a sustainable future

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PENTRONIC

+46 490 - 25 85 00, info@pentronic.se
Bergsliden 1, SE-593 96 Västervik, Sweden
www.pentronic.se

Order receipt: order@pentronic.se
Complaints: quality@pentronic.se
Job applications: rekrytering@pentronic.se
Invoice e-mail: invoice@pentronic.se
Accredited laboratory: akl@pentronic.se

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Text: Janne Larsson, Dan Loyd, Pentronic
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FROM THE MANAGING DIRECTOR

Commitment and professionalism

Today, when the new copy of It's About Temperature is published, I've been employed at Pentronic for about one year. It has been a year full of new impressions and my primary focus has been to understand the business and our customers' needs. I hope this year's edition of our magazine will inspire you and provide interesting reading.

My high expectations have been exceeded.

– Pentronic is an extraordinary company, at 50 years of age it stands on solid ground and still vital with a desire to continue to develop.

My first year has offered several challenges as I have moved from the construction industry and a process-oriented manufacturing into manufacturing of complex, assembled customized products in small batches which Pentronic represents. The transition has gone very well, thanks to all competent and engaged colleagues in addition to the strong team spirit within Pentronic.

The same feeling of engagement and professionalism as I have experienced in my first year at Pentronic is something which we also aim to bring to our customers. One of Pentronic's core values is competence – we are experts within temperature measurement and through our considerable experience we have gained extensive knowledge of most of our customer's application needs.

We are passionate about our customers and their success is our success - Pentronic is and shall remain a partner which offers customized solutions to always meet our customers' high requirements. Together with our customers, we create value and build sustainable, long-term partnerships.

The team at Pentronic is looking forward to an exciting future with you where we together take on the measurement technology challenges of tomorrow!

/ Claes Arnesson, Managing Director




IT'S ABOUT TEMPERATURE



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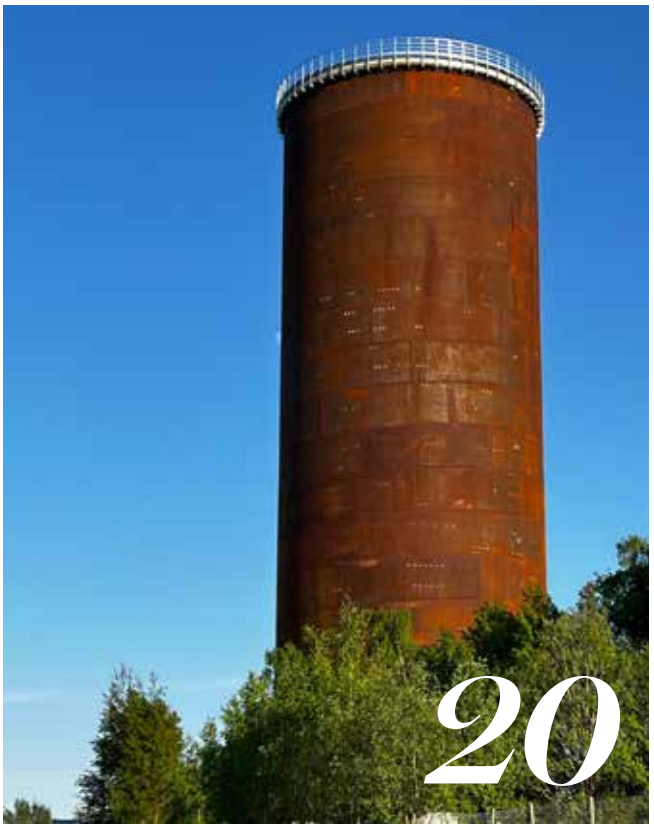
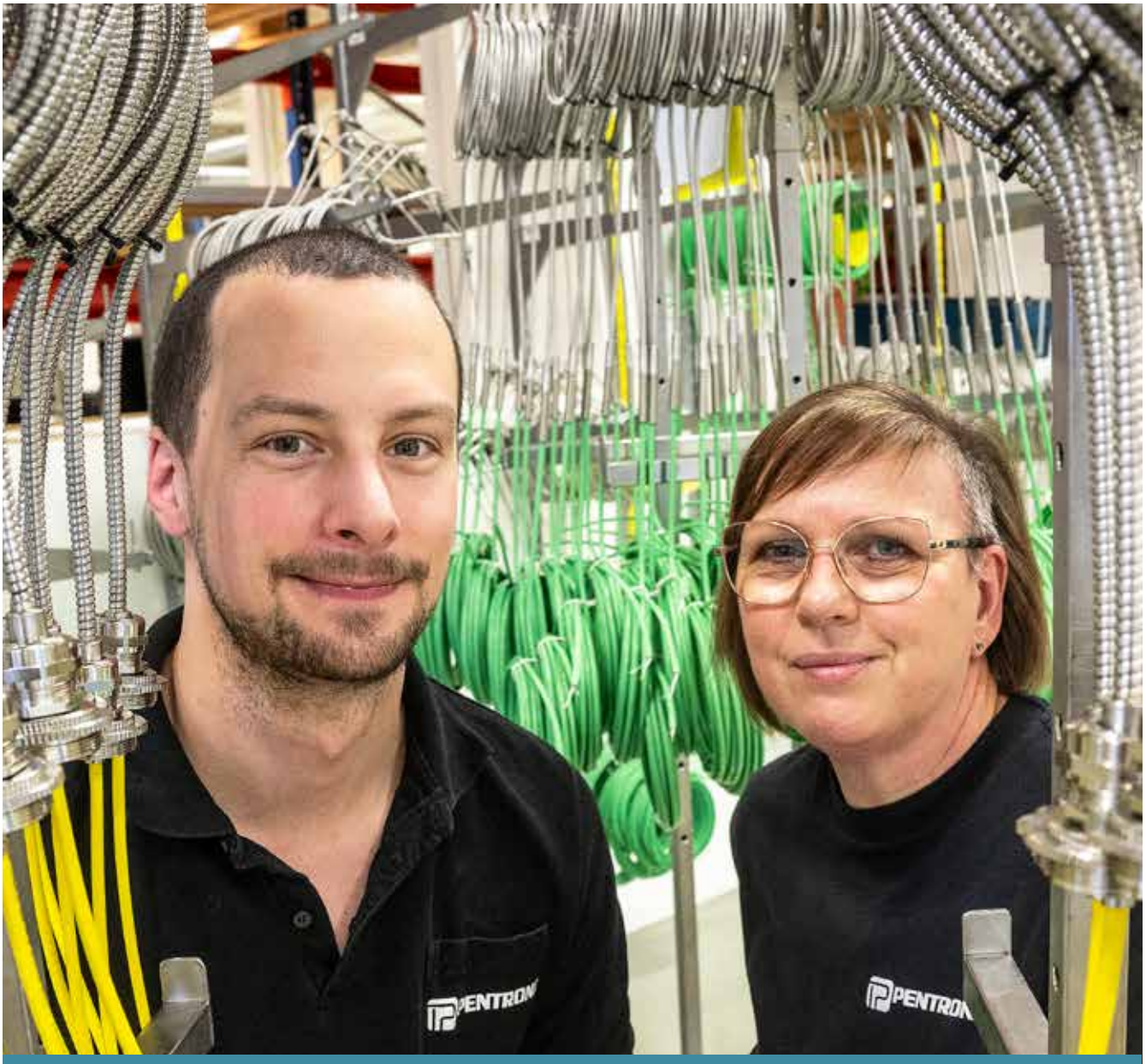




“**Sustainability** is a natural part of our **day-to-day work**”

Assemblers Tommy Månsson and Monica Magnusson.

Through commitment, expertise and great flexibility, Pentronic's employees are contributing to the transition to sustainability. "We have a responsibility to work on sustainability and have taken several initiatives to develop in this area," says Managing Director Claes Arnesson.

FOR NEARLY 60 YEARS, PENTRONIC'S business concept and aim have been to help customers gain greater energy efficiencies and develop their processes. Temperature monitoring is an essential parameter to consider during fossil-free steel development, energy containment construction and battery testing. These are just a few examples of the applications where different types of thermometer are needed in the development of modern, sustainable industry.

Continuous product development

Here at Pentronic, we always put measurement technology first. We know how important it is to measure as accurately as possible and at the best possible place in a process. As a result, many sensors are specially adapted to suit specific applications.

"We manufacture some of our sensors in larger, recurring production batches, but even these are in some way unique to us at Pentronic," says Product Development Manager Erik Gullqvist and continues:

700

Pentronic develops on average 700 new products every year

The UN's 17 Sustainable Development Goals

GLOBAL GOALS
for sustainable development

On 25 September 2015, the UN member states adopted Agenda 2030, a universal agenda for sustainable development comprising 17 global goals to be achieved by 2030. The global goals themselves contain 169 sub-goals and around 230 global indicators for how the work is to be conducted and followed up. The global goals and Agenda 2030 represent the most ambitious agreement for sustainable development ever adopted by world leaders.

Overall sustainability goals for 2030

People
100% engaged people

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

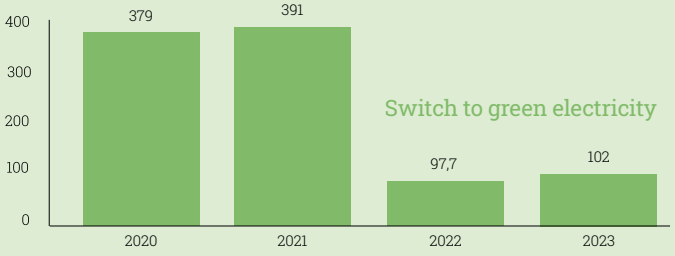
Environment
CO_2 neutral

- 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

Total greenhouse emissions Pentronic (scope 1 and 2)




Assembler Jessica Bergman.


Assembler Tobias Gunnarsson.

10%

of turnover is devoted to development and innovation.

"We have been in business for many years and have around 30,000 different items in our product range. Some people might think that by now we should have all the variants, but the reality is that as our customers' needs change we have to continue developing our methods."

Energy efficiency is an example of an area that is more important than ever.

"When a customer equips a newly developed machine with temperature sensors, you realise how important it is to pay great attention to where and how the temperature is monitored. In recent years we have developed integration of signal processing into the sensors, and this also imposes greater requirements on how they are manufactured," says Erik.

2%

of employee time worked is devoted to competence development.

High quality

Great variety and flexibility are the hallmarks of Pentronic as a workplace. Because no two products are the same, the work is extremely varied. A core characteristic of the company is that everyone takes personal responsibility for the product they produce.

"As a rule, an employee works on the same sensor throughout the entire production process until the finished product is submitted for final inspection. We find that we maintain a high level of quality if our employees are allowed to take personal responsibility for the entire process," says Oscar Riis, HR Generalist at Pentronic.

"This is a challenge for us when we are looking for new employees, but in return we get highly qualified and committed colleagues," Oscar continues.

Personal responsibility and expertise characterise the whole company.

"In order to best serve customers in different industries, we must understand many different processes," explains Marketing and Sales Manager Björn Tunek.

"Chemistry, thermodynamics, mechanical engineering and materials science are familiar areas for us. Through the development of integrated signal conversion, Pentronic's product development department has grown and now has formidable expertise in hardware and software development," continues Björn.

Staff retention rate

93%

Are you our next employee?

Pentronic is constantly on the lookout for new employees with a wide range of skills. Because we are part of Indutrade, our employees have many exciting development opportunities plus a wide network of colleagues around the world. For more information, please contact us. You can also submit an unsolicited application via our website: **www.pentronic.se**

Laboratory Manager Andreas Holm.

Sustainability in multiple dimensions

Our sustainability work in the form of high quality and accurate solutions for our customers has always been a focus area for Pentronic. As time has gone by, we have gradually provided further added value.

"We have a responsibility to work towards sustainability, and this includes for our own part – in our own operations. There are aspects that need to be considered both in terms of our employees and the local community in which we operate. Our efforts here can make a big difference. This is why we have taken several initiatives to develop in this area," says Managing Director Claes Arnesson.

Recently, Pentronic launched a local sustainability programme, directed at private individuals and associations within our vicinity. In this programme, the relevant initiators can apply for grants of up to SEK 50,000 for projects that contribute to achieving one of the UN's 17 global sustainability goals.

"We want to help ensure that more ideas can become reality in the locality where we live and work. Our involvement and contribution as a company are important both for the community and for our employees."

Sustainability programme

Pentronic's sustainability programme started and was instituted in 2024. The programme is directed at private individuals, associations or organisations that run projects in our vicinity (the Västervik region). Its purpose is to support projects that have a clear link to one of the UN's 17 global goals for sustainable development. Applications for project grants are submitted via Pentronic's website. A decision as to which projects will be awarded funding is taken twice a year. Scan the QR code for more information.

Number of participants 2023 on Pentronic's ST1 and ST2 training courses

81

Strong focus on work environment and wellness

100% engaged people – this is one of the goals of Indutrade's longterm sustainability strategy. It is very much about employees feeling well and being able to develop within the organisation. Ensuring long-term access to the right competence within the Group is also a major focus area.

TO ACHIEVE THE GOAL for 2030, we need to focus on leadership and competence development, and build inclusive teams and workplaces where people can thrive.

"If you build teams with diversity, this increases their capacity for development and innovation," says Desiré Haglund, Head of Sustainability at Indutrade.

Planning new premises

The basic requirements for everyone's wellbeing are safe and healthy working conditions.

"Investment in improved work and production environments is something we prioritise, support and encourage within Indutrade," says Desiré.

Pentronic is beginning to run out of space, and the company is planning to invest in new premises.

"Our intention is to consolidate our operations in a single new, shared facility," says Managing Director Claes Arnesson.

Claes asks Desiré what Pentronic should bear in mind from a sustainability perspective when planning new premises.

"The most important aspects are energy efficiency and investing in the use of renewable energy. Sustainable construction practices and choosing non-toxic materials with a small climate footprint are also important, as is creating a good and safe work environment for all involved," says Desiré.

Health for all

Enjoyment of one's work and general wellbeing come high up on the list of priorities in Pentronic's HR work.

"Our employees are the basis of our business. If they are all fit and healthy and enjoying their work, we will do a good job," says Claes.

"We regularly monitor our employees' sense of wellbeing, and we work extensively on health matters and the provision of wellness offers. As a result, the use of our wellness offer has increased from 25% to 75%."

"Part of this is that many employees take lunchtime walks on a daily basis. It happens spontaneously and is important socially, as well as providing exercise in the fresh air. The fact that we are creating this kind of culture is very much appreciated. If we are to remain fit over the long term, we need to get the right balance between work and personal life", says Claes.

Claes Arnesson, Managing Director.

New Indutrade Group structure for continued growth

At the end of 2023, Indutrade launched a new Group structure. The Group is subdivided into five business areas with a clear strategic focus on different business segments and technologies.

PENTRONIC IS PART OF the Technology & Systems Solutions business area. It mainly comprises businesses with their own products, based on advanced technical solutions and their own inhouse development, design and manufacture. The companies sell measurement systems, sensors, control and regulation technology and monitoring equipment to a number of different sectors.

" For us, this creates opportunities to identify potential for cooperation between companies with similar technologies and to network with each other," says Managing Director Claes Arnesson.

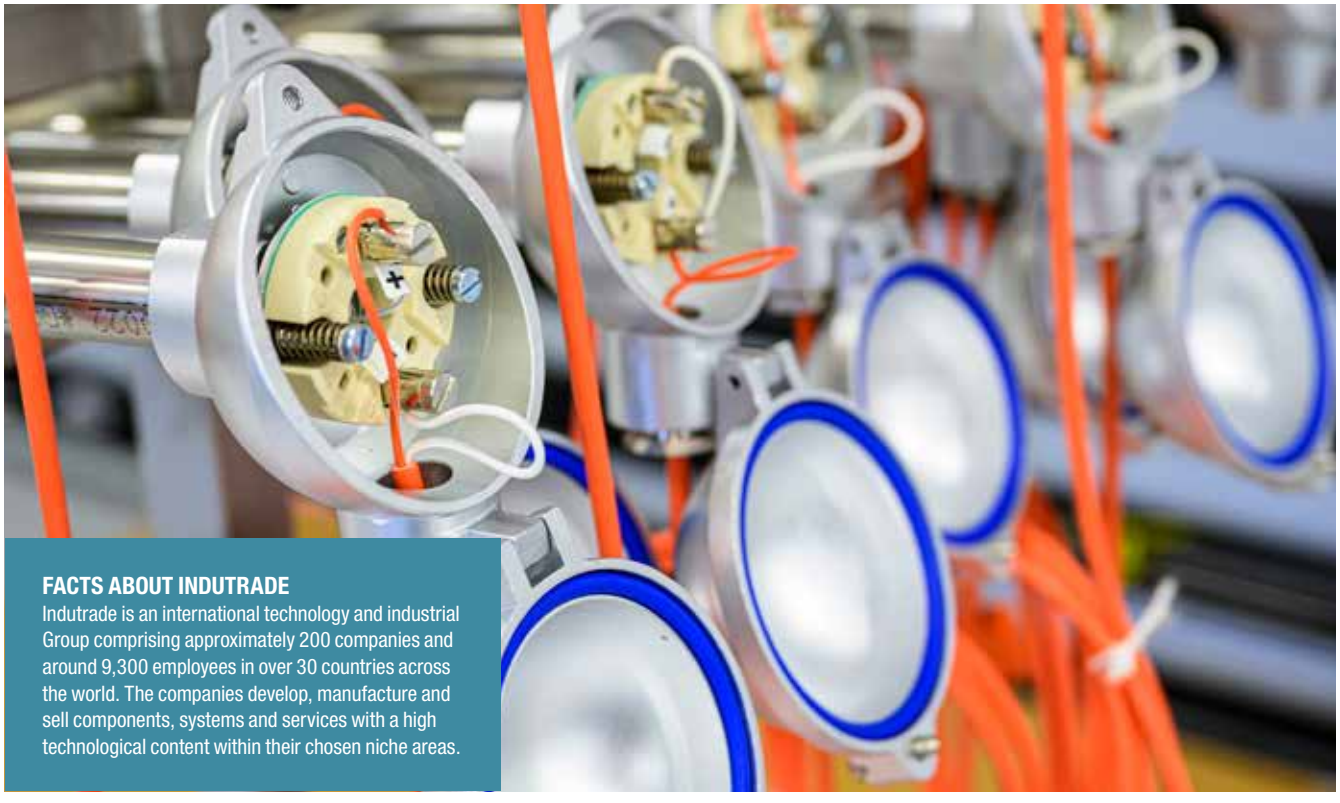
Head of Sustainability Desiré Haglund also sees great potential for better utilisation of the collective knowledge and expertise available in the Group and for promoting the sharing of such expertise between companies within the same market sectors and segments.

" I believe this will lead to very positive developments in many areas, with sustainability having a role to play," she says.

"Indutrade continues to nurture its value-based culture, with a long-term focus on people, entrepreneurship and decentralisation. This has long been the key to its success."

Desiré Haglund, Head of Sustainability at Indutrade AB.

Find more information at **www.indutrade.se**



FACTS ABOUT INDUTRADE

Indutrade is an international technology and industrial Group comprising approximately 200 companies and around 9,300 employees in over 30 countries across the world. The companies develop, manufacture and sell components, systems and services with a high technological content within their chosen niche areas.

"The actual results confirm that our **sustainability work is reducing the carbon footprint"**

Sustainable business requires us to conduct operations with an eye to the future.

"Generally, we want to ensure that sustainability is integrated in the companies' normal business strategies and core activities," says Desiré Haglund, Head of Sustainability at Indutrade AB.

INDUTRADE'S SUSTAINABILITY STRATEGY is based on ensuring the companies in the Group develop and improve in a financially, environmentally and socially responsible manner.

"Sustainability issues need to be integrated in the business strategy if we are to achieve sustainable, profitable growth that creates value in the long term," says Desiré.

The green transition

The natural focus of the sustainability work must be on customers, employees and continuous improvements. Pentronic uses specific goals and targets to reduce its carbon footprint.

"As a company, we take responsibility and adopt a long-term view. This requires us to consider sustainability in all the strategic priorities we adopt," says Managing Director Claes Arnesson.

"We work on achieving efficiencies through continuous improvements. The work is never-ending and constantly ongoing. We use electricity from renewable sources and have phased out fossil fuels, replacing them with wood pellets. We have installed efficient ventilation units in our premises," informs Claes.

The demand for fossil-free energy is increasing, and the targets for the green energy transition are higher than ever. This imposes new requirements on the development of tomorrow's products.

"It is a huge transition which is now gaining speed. So much is happening, and I think it is positive that Pentronic is well prepared for the green transition", says Desiré.

Contribute to sustainable customer value

Pentronic and other companies in Indutrade contribute in various ways to sustainable customer value. This is achieved, for example, by offering products and solutions of high quality and long service life which promote sustainable development.

"Good knowledge of customers' systems and processes, combined with a high level of technical expertise in the companies, will in many cases, streamline customers' operations and offer solutions that reduce environmental impact." says Desiré.

A key issue is how to stimulate the development and sales of products that have sustainable added value.

"In particular, we try to ensure that new products that are launched use less energy and/or reduce the carbon footprint," says Desiré.

"Already in the development phase, we need to bear this in mind when selecting materials and create an efficient manufacturing process. The right product for the right application allows the customer to save energy. For example, more exact temperature measurement will result in more efficient processes," continues Claes.

"Knowledge and adaptation are important aspects of the added value Pentronic offers its customers. Added value can also take the form of ergonomic improvements, an improved work environment and the safety a product contributes to the customer's operations," adds Desiré.

Pentronic is keen to engage in close cooperation with its customers.

"We are often at our customers' sites or participating in their operations. We measure and adapt the measuring equipment to ensure it best meets the customer's needs. However, we do need to be more adept at demonstrating the sustainability aspects of our products and explaining the added value we provide through them," says Claes.

Reducing its carbon footprint

Indutrade has joined the Science Based Targets initiative.

"Our ambition is to further develop our climate targets so that they are in line with climate science. We are convinced that this commitment will benefit Indutrade as a group and our individual companies in many ways," says Desiré.

The climate issue and reduced emissions are critical for sustainable business with an eye to the future.

"The transition to an economy with low carbon dioxide emissions involves many different initiatives on the use of energy and resources. We have a strong focus on initiatives that contribute to reducing our carbon footprint."

Training is one aspect of the work designed to achieve positive outcomes.

"In our latest analyses we saw a reduction of our carbon footprint in absolute numbers, despite the fact that Indutrade is also growing. This is a very positive outcome and shows that the companies in the Group are achieving much in their sustainability work," acknowledges Desiré.

Indutrade has been measuring the carbon footprint at Group level since 2020. The goal is to become Scope 1 and 2 CO_2 neutral. This relates for example to vehicle fuels and energy consumed in production processes and for heating premises.

"We are now also addressing our indirect impact in the value chain. It is more difficult to measure, but we have now seen our first figures and have gained a good idea of where we can make the greatest difference. It comes down to the materials we use in our products and the energy consumed when the products are used."

Code of Conduct

In Indutrade's sustainability work, the Code of Conduct is a policy to which the Group's companies should adhere.

"We also have an external code. This consists of relevant requirements we can impose on our suppliers and business partners. Both codes are currently being updated to provide an even better match with our own and our stakeholders' ever-increasing expectations," says Desiré.

"It is reassuring to have an owner like Indutrade with such a strong focus on sustainability," concludes Claes.

INDUTRADE SUSTAINABILITY AWARDS

This is the third year of the annual Indutrade Sustainability Awards. There are awards in three different categories: People, Environment, and Products & customers.

Meet Lina, Camilla and Rebecca

Putting your own signature on an order and handing over a great product is like signing a painting!

This is how Lina, Camilla and Rebecca describe the feeling after constructing and manufacturing a temperature sensor.

THEY WORK IN PENTRONIC'S PRODUCTION FACILITIES.

Camilla Berg is a "returnee", Rebecca Karlsson will have been working for two years this summer, and Lina Dahl was appointed in December of last year. The production process is, to a large degree, craftsmanship requiring extreme accuracy and precision.

"This is a job where you get to challenge yourself considerably, and continuously improve your skillset, whilst taking pride in creating a handcrafted product." says Camilla.

" You have to be dexterous, want to work with your hands, have a sense of detail and be able to deliver an aesthetically pleasing product of high quality," add Rebecca and Lisa.

Refine your techniques

All three appreciate the variety of their job and the opportunities for development.

"We have standardised working methods to adhere to which we have the opportunity to refine together, by discussing our way of working and jointly developing methods to achieve the best results", says Rebecca.

Refining your techniques might mean learning how strong your welding flame should be, or the actual hand grip when silver soldering a component.

"It might also be which of the different tips you should use on a soldering iron and finding a method that suits you best."

"Constant and continuous work on improvements also leads to a lot of suggestions for improvements in the activity as a whole."

What are your views about the atmosphere at work and getting on with your colleagues?

"There's a lot of humility, flexibility and team spirit," say Camilla, Rebecca and Lina.

They point to the sense of enjoyment, the excellent work environment, the fact that they have been fully accepted by their workmates, and the benefits of flexitime work.

"There's no sense of hierarchy: when you are new, everyone shows humility and is eager to show you how they do things. We learn from each other, and by seeing how others do things, you can really learn a lot," say Rebecca and Lina.

"In my experience everyone is very welcoming. You're well looked after when you're new," continues Camilla.

Unsolicited application

Rebecca started at the Pentronic production facility in Västervik in June 2022.

Lina Dahl, Camilla Berg and Rebecca Karlsson works in Pentronics production. The appreciate the variety in their job and the opportunities to be able to develop.

"When I telephoned and applied for a job, Pentronic already had my CV, as I had previously submitted an unsolicited application. When I started, the production department was having to work very hard in the run-up to summer and there were many customer orders to deliver, but I learned a lot very quickly," says Rebecca.

"I worked with thermocouples throughout that time. I was amazed that the work involved so much craftsmanship. It's also really cool: I love the aesthetic side of things and being creative. I feel that I'm developing all the time, learning new things and getting better and better at welding and soldering our products."

Longed to return

Camilla may be viewed as a returnee to Pentronic and the production facility in Verkebäck.

"I left six years ago to look for a new challenge in my life and tried out other jobs, but after five years I longed to return, so I applied for a job at Pentronic again. By chance there happened to be a vacant position and it's fantastic to be back. I really enjoy both my job and working with my colleagues," says Camilla.

"Previously I worked with Pt100s, but I'm now making thermocouples. I can see a bit of a difference from things as they used to be. Nowadays we cooperate more across departmental boundaries, and that's a good thing."

Learning gradually

Lina Dahl has held her post at Västervik since December 2023. After previously working as a seamstress at a well-known company in the region and then taking maternity leave, she was on the lookout for a new challenge. Lina thinks that diversity and gender equality enrichen a workplace, and she encounters this in her work at Pentronic.

"I think it's good that there are men and women of varying ages – it generates a good group dynamic," she says.

Lina was recommended to apply for a job here by her mother-in-law, who also works at Pentronic. She was taken on as an assistant in the thermocouple department. Soldering and welding were techniques that were completely new to her, but she quickly worked her way into her new job.

"I'm now workingwith Pt100s. I knew the products Pentronic manufactures but didn't realise so much craftsmanship was involved. What I do now is a bit different, as I was stitching camouflage netting before," says Lina.

LINA DAHL
Has been working in the production facility in Västervik since December 2023.
Home life: Lives with her husband and two children, aged three and one, in Björnsholm north of Gamleby.
Free time: Enjoys travelling with the family around Sweden to various destinations such as Kolmården etc.

CAMILLA BERG
Returned to Pentronic and the production facility in Verkebäck in December 2023.
Home life: Lives with her husband in Verkebäck, has two grown-up children, three grandchildren and one stepchild.
Free time: An artist who paints various kinds of subject and exhibits in Stadsparken in Västervik in the summer. Together with her husband, Camilla has opened a second-hand shop in Västervik. Enjoys cross-country running.

REBECCA KARLSSON
Has been working in the production facility in Västervik since June 2022.
Home life: Lives with her partner and three-year old daughter in Västervik.
Free time: Devotes her time to her daughter's activities; very interested in gardening and is planning a kitchen garden; also enjoys downhill skiing.

They are the voice and face of the company

Annelie and Kristin are generally the first people that you meet at Pentronic. "We're in contact with the entire world! Nowadays it is usually via email, but we also take telephone calls from customers when they need help with a product or solution," say Annelie Appelqvist and Kristin Johansson.

THEIR MAIN TASKS are to act as order administrators and sales support for Pentronic's sales organisation.

"We function as a spider in the web. We administer orders from start to finish, from the initial order confirmation to invoicing customers."

Every day, Kristin and Annelie enter lots of orders in the system. They answer the telephones and act as receptionists for visitors. They check that information in the system matches the customer's order, for example, that the correct delivery address is entered for goods to be sent to customers.

"As sales support, we also have direct contact with the sales staff, as well as helping our customers."

Important service role

They both like the variety inherent in their work, which also requires them to be very flexible.

"The most enjoyable part is providing good service, both internally and externally, and being able to relieve the pressure on our sales staff," maintains Kristin.

During their time at Pentronic, they have witnessed the constant product development and the fact that the orders generally involve special and tailored solutions for customers in many different fields and industries.

"In our contacts with customers we encounter, for example, questions relating to the flow of a product: it may relate to a certificate or be linked to freight, export or customs handling," says Annelie.

Experienced multitaskers

During their journey, Kristin and Annelie have had a number of different duties within administration and have gained a lot of experience.

"I joined Pentronic in 1997 and was taken on as a temporary replacement for a pregnant employee in the finance department," explains Annelie.

One year later she got a new temporary position and new duties. Since 2005, Annelie has worked on handling orders.

Kristin, who started in 2013, has the same role. She has previously worked at a manufacturing company and also the Swedish Tax Agency. After a time, Kristin realised that she preferred working at a manufacturing company and tried to find a way back, but now to a somewhat larger employer.

"I had a very positive impression of Pentronic and submitted an unsolicited application 18 months before I actually started. When I got the post, I realised immediately that I had come to the right place. The job involves being able to keep track of a lot of things at the same time. I really enjoy my work," says Kristin.

What do you think are your main challenges?

"Because each product item is individually crafted, every order is a challenge. Sometimes we have to be able to quickly meet an urgent need from a customer. This can involve producing an item and then arranging the best possible delivery method," says Annelie. "It's also satisfying when orders are running as normal. At the same time, it requires us always to be a reliable supplier," says Kristin.

ANNELIE APPELQVIST

Has been working as an order administrator and sales support since 2005. Started at Pentronic in 1997. Has worked in the finance department, on mail handling, the switchboard, administering Pentronic's training offering and courses, the inhouse newspaper Stoppextra, and was for a time on Goods Check-Out.

Home life: Lives with her husband in an apartment in Västervik.

Free time: Her main interest is taking trips out in their motorhome, exploring different places in the vicinity and strolling around little towns. She also enjoys going out on the water on her SUP board. The pair also attend dance courses in modern fox and are helping keep dance band culture alive.

KRISTIN JOHANSSON

Has been an order administrator and sales support for Pentronic's sales organisation since 2013.

Home life: Lives in a detached house in Västervik – married and have a nine-year-old son.

Free time: Very involved in her son's activities, such as floorball and football training sessions. Enjoys working in the garden and being out and about in the countryside.


» We function as a spider in the web. We administer orders from start to finish, from the initial order confirmation to invoicing customers. «

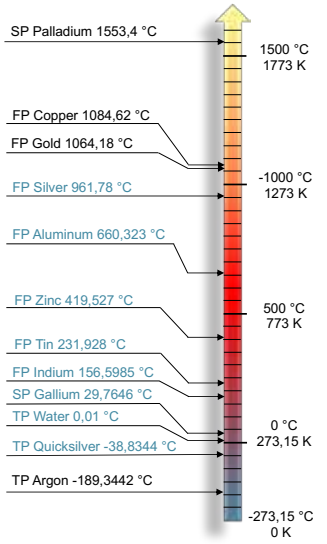
DID YOU KNOW THIS ABOUT **TEMPERATURE?**

Read more about temperature at Pentronic's website.

Fixed points

- FP, the freezing point, is the point at which a metal transitions from a liquid to a solid form.
- MP, the melting point, is the point at which a metal transitions from a solid to a liquid form.
- TP, the triple point, is the point at which the three phases of a substance coexist in thermodynamic equilibrium. Solid, liquid and gas.

For a number of metals, the temperature for FP and MP is defined on the basis of the International Temperature Scale of 1990 (ITS-90).



TP = Triple point • FP = Freezing point
MP = Melting point
Pentronic's accreditation covers fixed points shown in blue.

Vipers detect radiated heat

Pit vipers (Crotalinae), which belong to the viper (Viperidae) family, use infrared radiation (IR radiation) when hunting in the dark. The radiation is detected by two heat-sensitive organs, located between the eyes and the nostrils.

Brewed coffee at the right temperature

The right temperature for brewed coffee requires the water to be kept at 92–96°C once it comes into contact with the coffee. Within this temperature range, the water absorbs the right amount of fragrance and flavour, which ensures the best-tasting coffee. If the temperature is higher, the taste will be acrid and bitter. If it is lower, the coffee will be less full-flavoured.

The best temperature for serving coffee is usually between 68.3°C (155°F) and 79.4°C (175°F) – this ensures that the coffee's flavour can be enjoyed to the full without it being too hot to drink. If coffee is served too hot, the nuances of its flavour are hidden, but serving it too cold will equally mean that the flavour falls below expectations. A good piece of advice is therefore to aim for this temperature range, as it is generally regarded as the ideal temperature at which to enjoy the taste of coffee.

Thermometers through history






1500 Thermoscope
1600 Galileo thermometer
1620 Mercury thermometer
1650 Spirit thermometer
1800 Bimetal thermometer
1820 Thermo-couple
1885 Resistance thermometer
1900 IR pyro-meter
1930 Thermistor
1965 Quartz thermometer
1980 Thermal camera
1985 Ear thermo-meter

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.

CUSTOMER CASE

Västervik gets a new landmark in the form of a 70-metre high accumulator tank for district heating.

"The investment plays an important role in our work to meet the 2030 global goals," says Ture Nyholm, Project Manager at **Västervik Miljö & Energi AB (VME).**

Impressive symbol of a **sustainable future**

Ture Nyholm, Västervik Miljö & Energi, Viktor Svahn, Sales Engineer at Pentronic and Björn Tunek, Sales Manager at Pentronic.

SINCE DISTRICT HEATING WAS INTRODUCED in Västervik just over 40 years ago, air quality has improved as the emissions from oil-fired boilers have disappeared. Around 90% of the properties with access to district heating are connected.

The power plant, Stegeholmsverket is Västervik Miljö & Energi AB's facility for electricity generation and district heating production. The majority of heat energy is supplied to industry, municipal housing properties, the hospital, schools and other major properties and facilities.

Recipient of "Klimatklivet" investment grant

An exciting step is now being taken to meet the green transition and a future involving increased electrification.

During the autumn, the new accumulator tank with hot water, is due to be commisioned. The water will be at a temperature of 99°C, and the tank has a capacity for storing 1,000 MWh of energy. The tank, which stands around 70 metres high, is intended to act as a heat buffer in the district heating system and lead to more efficient production of district heat.

"The accumulator tank brings stability to the district heating

system and increases security of supply to our customers," says Ture.

"In addition, there is less need to add peak heat, based on fossil fuels, when energy consumption is high."

The project has been awarded the Swedish Environmental Protection Agency's "Klimatklivet" ("Climate Leap") government investment support. This support is earmarked for measures that help reduce carbon dioxide and other greenhouse gas emissions in order to meet the 2030 global sustainability goals.

Temperature sensors in the pump house

Pentronic is supplying measuring equipment for the pump house which plays a central role in the project.

"Three pumps are being installed in the pump house for the district heating network, as well as a charging pump for the accumulator tank. Temperature sensors measure water temperature on the outgoing district heating water and shunts to ensure the supply pipe temperature in the network is correct," explains Ture.

"The accumulator tank is charged with hot water when there is an excess in the district heating network and is discharged when there is a high demand and need. The demand can be particularly high during the cold morning hours and when a lot of Västervik residents use large amounts of hot water at the same time."

Project on home ground

Because Pentronic has its production facilities in Västervik and Verkebäck, it is a local supplier for the project.

"For us, it's really exciting to be able to participate in an environmental project like this and get to work on home ground," says Björn Tunek, Sales Manager at Pentronic.

Viktor Svahn, Sales Engineer at Pentronic, is the point of contact with the client.

"We are supplying Pt100 sensors for the pump house – these are air temperature sensors with various accessories. In addition, there are temperature transmitters for temperature measurement where very high accuracy is required in critical applications. It is an exciting project; it is interesting to see and follow installations and the full construction process," says Viktor.

Ture also sees value in their vicinity to each other.

"This is important in terms of the service we get from Viktor and Pentronic. They delivered all the equipment in good time so that we could keep the schedule. They helped us with measurements and final calibration of the equipment. Working with a local company on a project like this is a valuable asset."

Unique welding method

The team of welders that built the accumulator tank first completed the bottom section on foundations 80 cm deep, containing more than 30 tonnes of rebar.

"The accumulator tank sits on a sound foundation, as the ground contains moraine," Ture assures us.

"It is reassuring that Swedish steel from SSAB was also used in the construction."

Once the bottom section was ready, the roof section was welded. Using the so-called spiral method, the entire structure then took shape. This method involves welding on plates in succession inside the structure and then forcing it up until the accumulator tank achieves its full height. The tank consists of a total of 500 tonnes of steel plate and is well insulated to retain the heat and minimise heat losses.

"It will be clad in aluminium sheets, and its design is meant to symbolise an hourglass turned seaward, facing the entrance to Västervik," says Ture.

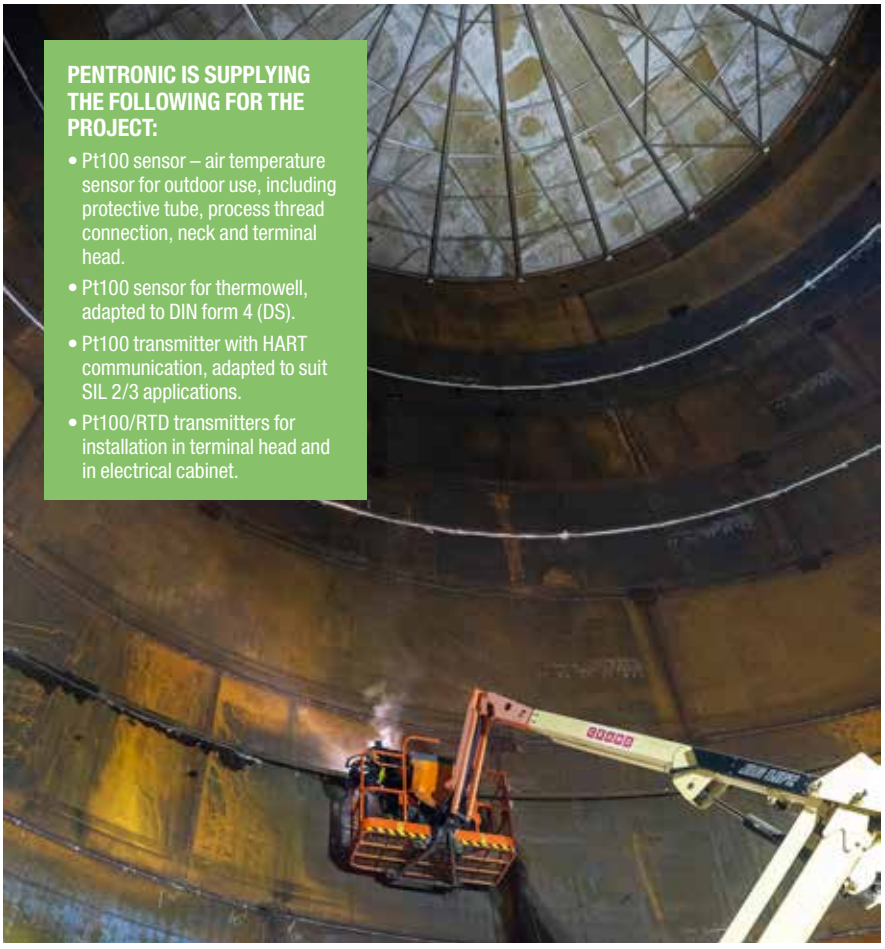
A sense of pride

Non-pressurised accumulator tanks are never fully filled with water, rather they have a steam cushion to keep the pressure in equilibrium and so that the water can expand when the water temperature increases.

"We will fill the tank with cold, oxygen-free water. We do this to prevent corrosion and to have an oxygen-free environment in the tank until steam can be added via a pipe from the heating plant."

What does it feel like to be able to manage a project like this?

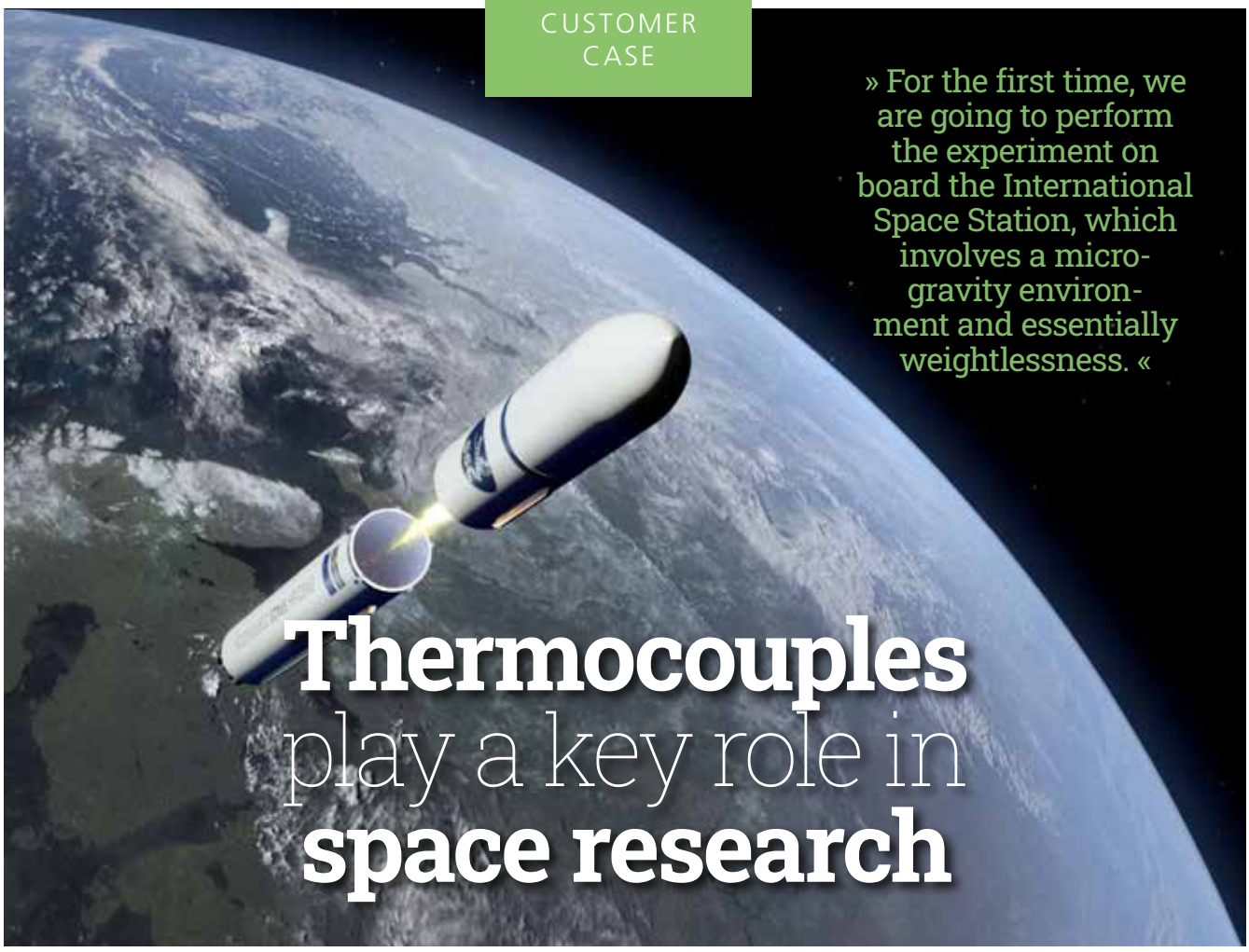
"Exciting! I feel a sense of pride at Västervik's new landmark which contributes to our district heating production and enhances the environment," says Ture.



PENTRONIC IS SUPPLYING THE FOLLOWING FOR THE PROJECT:

- Pt100 sensor – air temperature sensor for outdoor use, including protective tube, process thread connection, neck and terminal head.
- Pt100 sensor for thermowell, adapted to DIN form 4 (DS).
- Pt100 transmitter with HART communication, adapted to suit SIL 2/3 applications.
- Pt100/RTD transmitters for installation in terminal head and in electrical cabinet.

CUSTOMER CASE



» For the first time, we are going to perform the experiment on board the International Space Station, which involves a micro-gravity environment and essentially weightlessness. «

Thermocouples play a key role in space research

The state-owned space company Swedish Space Corporation (SSC) facilitates top-level research in cutting-edge technology out in space.

"In experiments in physical chemistry (materials research), thermocouples are a key component in allowing highly accurate regulation and measurement of temperature based on scientific principles."

THIS IS THE VIEW of Kenneth J Henriksson, Mechanical Design Engineer at SSC, stationed in Solna where the company has its head office and development centre.

Microgravity research

Since the early 1970s, SSC has helped space organisations, companies and researchers gain access to space. The company is active throughout the world. For example, it has one of the world's largest global networks of ground stations for satellite communication as well as Esrange Space Center base outside Kiruna, which acts as a launch site for research projects on board rockets and balloons.

SSC designs, develops and tests different types of space systems, rocket systems and experimentation equipment for research in space environments or simulated space environments. By participating in a large number of experiments, the company has accumulated considerable knowledge about equipment for atmospheric, ionospheric and microgravity research in a number of areas, including material physics and biology.

A very compact gradient furnace that SSC built for these experiments includes small heaters where thermocouples from Pentronic are installed. The thermocouples must not be larger than 0.5 millimeters in diameter.

The first time in orbit

In addition to noteworthy plans to start launching satellites in 2025, SSC also works with scientists from across the world on projects designed for ISS, the International Space Station.

A new research project in metallurgy is designed to investigate crystal structures in aluminium alloys by controlling the melting and solidification of the latter under very strict conditions.

"For the first time, we are going to perform the experiment on board the ISS, which involves a microgravity environment and, in principle, weightlessness," explains Kenneth.

The project is aimed inter alia at identifying new and better methods for

the production of aluminium alloy parts using casting processes.

"Casting allows us to get closer to the final shape of the parts, so that minimum finishing is required. It is a more economically advantageous method compared to producing a forged or machined aluminium alloy part," says Kenneth.

One of the key factors

Research in this area has previously involved the use of parabolic flights with an aircraft or sounding rocket. This gives a time window of mere minutes to perform the experiments, whereas on the International Space Station experiments can take hours or even months.

"At the moment we are constructing equipment for the ISS. Our task is to enable researchers to conduct very accurate experiments where one of the key factors is temperature regulation down to a hundredth of a degree."

"The experiment involves investigating crystal formations in molten metal using X-ray imaging. Being able to do this in a gravity-free state reveals mechanisms which would otherwise have been masked by the Earth's gravitational pull," explains Kenneth.

The end customer is the European Space Agency (ESA), and the project is being carried out in collaboration with inter alia Airbus Defence and Space (Space Division).

Long partnership

Pentronic has delivered thermocouples for the project and is contributing via its cutting-edge expertise in temperature measurement.

"To monitor the melt and solidification of metal samples and be able to control the process in a precise manner, you need very accurate temperature measurement and thermocouples," maintains Kenneth.

SSC have built a compact furnace with very small gradients for these experiements that contains small heaters with thermocouples fitted to them.

"The thermocouples must not exceed 0.5 mm in diameter, and the furnace requires a specific type of heating wire."

SSC undertakes all the development, installation and most of the testing itself, but relies on third-party assistance for the finishing of complex parts.

"I have been working at the Swedish Space Corporation for 12 years, and for all that time and indeed before, Pentronic has been our partner for thermocouples in our experiments, including on sounding rockets," says Kenneth.

Some years ago, Pentronic held a company-run training course in traceable temperature measurement at SSC.

"Our partnership began when we needed to learn about temperature measurement, and that's when we engaged Pentronic. We develop all the electronics involving temperature sensors ourselves, so it's important that we understand temperature measurement."

Swedish Space Corporation has extensive experience and expertise in helping space organisations, companies and researchers from various countries by providing access to space for various investigations and experiments.

Kenneth J Henriksson, systems engineer at the Swedish Space Center.

Strict requirements specifications

SSC supports the UN's Agenda 2030 global goals for sustainable development. Products that are intended for use in space are subject to full traceability requirements, and there are strict requirements specifications for each component.

"Materials are chosen very carefully from an approved materials database," points out Kenneth.

The thermocouples Pentronic is supplying for the new experiment require a specific cable to gain approval.

"We use fully proven technology in our applications. In these cases, the customer will be more expert than we are, in that they know their process inside out," says Per Bäckström, Sales Engineer and Technical Expert at Pentronic.

Prepared to constantly meet **new challenges!**

Pentronic's production engineers are a shining example of employees who love the challenge of problem-solving.

"Each assignment is a new challenge, and the driving force is that we work together," say Göran Österberg, Edin Beganovic and David Zeylon.

IN TERMS OF NUMBERS, Pentronic's Production Processors are a pretty small team, but they play a central role in the company. Their role is to produce documentation containing instructions, drawing materials and manufacturing details for customer-specific products.

" We are in constant dialogue and work closely with both our sales organisation and the production facilities," they say.

" Our documentation must be clear. The documentation provides information about a product, including its dimensions, the operating temperatures it must be able to withstand, and whether protective fittings etc. are required."

High traceability

Pentronic's product range contains around 30,000 items in total, including all variants of a given product. Because these are customer-specific solutions, the Production Processors collective knowledge is extremely useful in their preparatory work.

" Our unique knowledge and considerable experience mean that we can look back at previous solutions, giving us a rich source of information we can consult when devising a new product," say Edin and Göran.

Requirements specifications today include materials certificates and high product traceability.

" Because each product that we manufacture is marked with its own ID, we have a high level of traceability for all our products. We also issue materials certificates, which are especially important in critical processes. For example, the food and pharmaceuticals industries place strict requirements on the materials used in our temperature sensors," says Göran.

Can also solve the impossible

The production engineers use a dynamic work method and help each other, which is a strength when it comes to complex assignments. One example is an application that was meant to meet three mutually conflicting criteria, with the consequence that it could not actually be manufactured!

" The product was meant to be gas-tight, easily replaceable and elastic. We managed to solve this by using several pairs of eyes and utilising each other's experience and knowledge," explains Edin.

Continuous product development, new applications and the climate transition lead to new challenges.

" For many customers, the main thing now is to transition to green energy, and this means new challenges for us," says Göran.

Extensive accumulated expertise

It is also an advantage that many of them have worked in the production department. Göran was taken on in 1983 and has produced most things when it comes to temperature sensors and thermocouples. He still has that same driving force within him, and Göran feels he is continuing to develop on the journey towards ever smarter solutions in temperature measurement.

" I have managed to be part of an incredible evolution and being able to work with so many exciting customers – as we do in different industries – is really interesting," he says.

Edin was appointed at the start of the century, also starting in the production department, where he worked for 15 years.

" Because I've manufactured every type of temperature sensor, I have considerable understanding of the products' various applications. I see my work as a challenging process, where I constantly challenge myself and grow in my professional role," he says.

David has been a member of the team since summer 2023. He has considerable experience from various employments within the industry.

" The beauty of Pentronic is that we devise and manufacture so many different products. The reason I applied for the job was mainly to be able to work with CAD, something I had never done before, and I have been involved in various projects," says David.

Exciting life journeys

Pentronic's production engineers can look back on some exciting life journeys. Edin grew up in Bosnia. On leaving the country, he arrived first in Germany where he worked for six years and met the love of his life, who brought him to Västervik.

" Once we had decided to live together and where we would live, I packed my bags and moved to Sweden in 1998. At the time, my girlfriend was already living in Västervik. I had been told what a fantastic place Västervik is, with its beautiful islands and skerries. That impression turned out to be completely true," says Edin.

Göran's roots are in Västervik; when he was taken on at Pentronic 41 years ago, there were only eight employees.

" An interesting episode was when we created goal-oriented production teams. It generated great commitment from everyone and was very successful," says Göran.

David also was born and grew up in Västervik. He is a committed joiner of clubs and societies and has now taken a new step in his career as a production engineer at Pentronic.

EDIN BEGANOVIC

Appointed in 2000 and worked initially in production for 15 years before subsequently becoming a production engineer.

Home life: Lives with his wife in an apartment on Östersjövägen in Västervik.

Free time: Likes the islands and skerries and nature in general; goes fishing and owns a a small boat together with a few buddies; plays tennis and goes mountain biking.

DAVID ZEYLON

Appointed in 2023. David has been employed for many years in various industrial companies and has also previously been a production engineer.

Home life: Lives with his wife and four children in a detached house in Västervik.

Free time: Very involved in his children's activities, plays padel tennis and floorball. Head coach of Västervik's women's team in floorball.

GÖRAN ÖSTERBERG

Taken on in 1983 at Albin Jansson's machine workshop which used to make temperature sensors. The business was later acquired by Pentronic. Göran has worked in production and has been a team leader, constructor, and then production manager with responsibility for personnel and scheduling, before becoming a production engineer in 2018.

Home life: Lives with his wife in a detached house on Hornsudde in Västervik.

Free time: Loves the islands and skerries; had a sailing boat for many years, but now has a motorboat. Rides his bike out in the countryside, sometimes also to work.

Contamination, corrosion and disconnect

– SOME OF THE MEASUREMENT ENGINEERS ENEMIES

Measuring the temperature of flowing liquids in a pipe system is not usually considered a particularly complex problem – rather, the reverse. However, if the liquid is highly contaminated, things can become tricky for the measurement engineer. If corrosion and/or disconnect in the measurement installation is also suspected, things can become really problematic. Temperature measurement in contaminated liquids requires a suitable sensor. This must then be positioned at a suitable location in the pipe system.

Unfortunately, in most cases there is no "best measurement installation" which would apply under all conditions. On the other hand, there will almost always be an optimal installation that satisfies certain requirements.

FOR THE PURPOSES OF DISCUSSING TEMPERATURE MEASUREMENT of contaminated liquids, we will consider a specific measurement problem. The temperature is to be measured near an S-bend in a pipe system as shown in Figure 1 below.

The pipe, which is made of stainless steel, has an outer diameter of 70 mm and a wall thickness of 3 mm. Water is flowing through the pipe, and the water may be clean or heavily contaminated. The water temperature is around 60°C, but it can quickly change to around 75°C before just as quickly returning to 60°C. The pressure in the pipe is 0.8 MPa and the flow rate is around 50 m^3/hour, resulting in a mean velocity of 4.3 m/s. The pipe system is sited in industrial premises having an air temperature of 15°C, and these premises can be very humid.

The contamination in the liquid will affect both the flow and the heat transfer in the pipe. Regardless of whether the sensor intended to measure the liquid's temperature is sited inside or outside the pipe, the contamination inside the pipe will affect the measurement result. We must also allow for the possible effect of corrosion on the measurement installation and that disconnect can occur on some sensor installations.

In industrial applications, the flow in the pipe is almost always turbulent and this can be determined using the dimensionless Reynolds number, Re.

$$Re = (w\,D)/\nu$$

where w is the fluid's mean velocity in m/s, D the pipe's inner diameter in m and ν the kinematic viscosity of the fluid in m^2/s. The kinematic viscosity of a given fluid depends inter alia on its temperature, T, in °C. For clean water, the following applies: $\nu = \nu(T) = \nu(60°C) = 0.477\ 10^{-6}\ m^2/s$. The Reynolds number will be Re = 580 000.

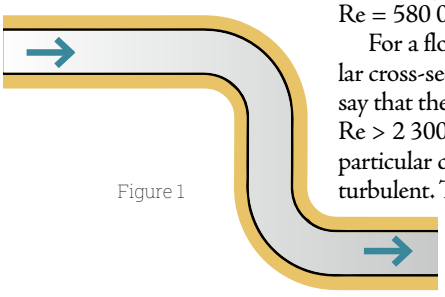


Figure 1

For a flow in a pipe of circular cross-section, generally we say that the flow is turbulent if Re > 2 300. The flow in this particular case is without doubt turbulent. The flow in the pipe is assumed to be fully developed. For a fully developed turbulent flow, the velocity profile is comparatively smooth, as can be seen in *Figure 2*. The mean velocity is then 82% of the maximum velocity.

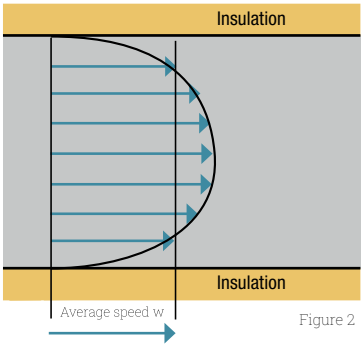


Figure 2

The straight entrance length required before the flow becomes fully developed is comparatively long. For a turbulent flow, the entrance length can in certain cases be as much as 50 pipe diameters. In many industrial applications, such long straight lengths are rare.

The straight lengths which, according to the literature, are required to obtain a fully developed turbulent flow are based on experiments. In most experiments, it is assumed that the straight pipe is connected to a large vessel containing a stationary fluid. In many industrial contexts, the entrance length may be estimated at 25 to 40 pipe diameters. Such a large variation is due to the fact that there are many parameters that will affect the extent of entrance length. If we assume that the entrance length is 40 pipe diameters, the entrance length in this case will be 2.6 m.

In most industrial applications, therefore, we cannot assume that the flow is fully developed. We have to accept this uncertainty about the exact appearance of the velocity profile. When calculating heat transfer and flow resistance for a sensor, we must be aware of this uncertainty about the velocity profile in the pipe. I will now discuss the use of insert probes and surface-mounted sensors upstream and downstream, respectively, of the pipe bend. I will also discuss an insert probe which is installed in the pipe bend itself.

Installation of an insert probe upstream of the pipe bend

We will begin by considering a sheathed thermocouple positioned in a protective tube upstream of the pipe bend, as shown in *Figure 3*. Let us assume initially that the liquid is clean water.

In the pipe there is a radial heat flow emanating from the liquid at a temperature of 60°C, passing through the pipe wall and insulation to the pipe's environment at a temperature of 15°C. This means there is a difference between the temperature of the liquid

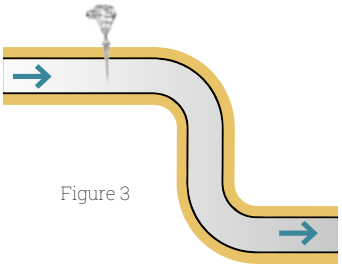


Figure 3

and that of the pipe wall. This in turn means that we have a heat flow along the protective tube and the sheathed thermocouple to the pipe wall. The measurement location in the thermocouple therefore measures a temperature which is somewhat lower than the temperature of the liquid.

If the pipe is well insulated, the heat flow from the liquid to the environment will be very small, and the temperature difference between the liquid and the pipe wall will also be very small. This means that the heat flow along the thermocouple to the mounting in the pipe wall is very small. The temperature that the sensor measures is therefore slightly below the temperature of the liquid.

In some types of installation, the pipe is allowed to be uninsulated. This may be due to, for example, an authority requirement. In such cases, the heat flow from the fluid to the environment increases, as does the heat flow along the protective tube and thermocouple to the wall. The measurement error increases. The exact degree of measurement error will depend inter alia on the protective tube's or the sheathed thermocouple's diameter and insert length, the thermal conductivity in the protective tube and thermocouple, the heat transfer coefficient between the liquid and the protective tube, and the temperature difference between the liquid and the pipe wall. The latter temperature difference is determined inter alia by the heat transfer coefficient between the liquid and pipe wall and the dimensions and thermal characteristics of the pipe and insulation.

We can estimate the measurement error as a consequence of the axial heat flow in the protective tube and sheathed thermocouple to the pipe wall. See:

www.pentronic.se/en/ > Menu > Archive Technical Publications > Properties and sources of error by thermocouples > Measurement error due to thermal conduction in a sheathed thermocouple

We will now consider the case where the fluid is highly contaminated and where both the sensor and the inside of the pipe have built up a thick coating, whose thermal conductivity is lower than that of the pipe wall, protective tube and thermocouple. See *Figure 4*.

If the thermocouple and pipe wall have built up a coating of contamination, this will affect both the heat transfer and the flow. In this context, the contamination can be seen as a form of insulation. This means that the temperature of the pipe wall drops and the heat flow along the protective tube and sheathed thermocouple is affected. The temperature difference between the liquid and the measurement location in the thermocouple increases, and so the measurement error increases as well. The thicker the coating, the greater the measurement error. The coating of contamination also means that the flow resistance in the pipe system increases.

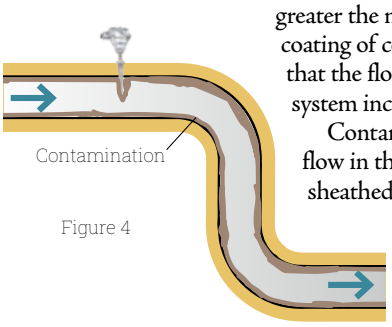


Figure 4

Contamination affects the heat flow in the protective tube and sheathed thermocouple to the pipe wall. For calculation of the measurement error:

www.pentronic.se/en/ > Menu > Archive Technical Publications > Properties and sources of error by thermocouples > Measurement error due to coating build-up

The heat transfer coefficient between the liquid and the protective tube is slightly reduced when the protective tube is contaminated. The coating of contamination can be seen here as insulation, which causes the heat flow from the fluid to the measurement location to be reduced compared to a situation where there is no such coating of contamination. In the event of a change in fluid temperature, the response time will therefore increase if the protective tube is contaminated. The thicker the coating, the longer the response time.

Installation of a surface-mounted sensor upstream of the pipe bend

We will now consider a surface-mounted sensor installed upstream of the pipe bend. See *Figure* 5. It is assumed that the pipe is insulated and that the sensor measures the external temperature of the pipe. An advantage of a surface-mounted sensor compared to an insert probe is that the former does not affect the flow in the pipe system. Let us now assume that the liquid is contaminated.

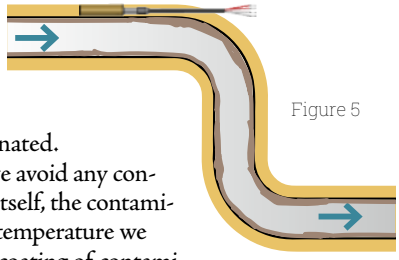


Figure 5

In this case, although we avoid any contamination of the sensor itself, the contamination will still affect the temperature we measure. The thicker the coating of contamination inside the pipe, the lower the heat flow to the environment. The coating of contamination may be seen as a form of insulation inside the pipe.

The temperature difference between the liquid and the pipe wall increases. The surface-mounted sensor measures the pipe's external temperature, which means that the measurement error increases. Even in this case, the temperature difference between the inside and outside of the pipe is very small.

If the pipe were uninsulated it would have a lower temperature than an insulated one, with the result that the measurement error would be greater. When a surface-mounted sensor is used, it is very important that the sensor makes good contact with the pipe. Contact paste should be used to ensure good contact.

Unfortunately, corrosion can sometimes occur between the sensor and the pipe, resulting in a temperature difference between the pipe and sensor. There will be an increase in measurement error. Often, corrosion builds up slowly, making it difficult to detect. A regular check is therefore needed on the measurement installation to make sure the surface-mounted sensor is making good contact with the pipe. If the pipe is insulated, the inspection will be more complicated, but it must still be carried out. After the inspection, the insulation must be reinstated, though it is unfortunately easy to overlook this when working under stress. This will lead to an unnecessary increase in the measurement error.

Normally there should be no disconnect between the sensor

and the pipe. If disconnect were to occur, this would dramatically increase the measurement error. On the other hand, if the measurement error becomes very significant, it does tend to make discovering a fault in the measurement installation easy. The response time is affected by the heat flow to the pipe and the pipe's thermal characteristics. The coating of contamination acts as a form of insulation, which reduces the heat flow to the pipe and lengthens the response time. The thicker the coating of contamination, the longer the response time.

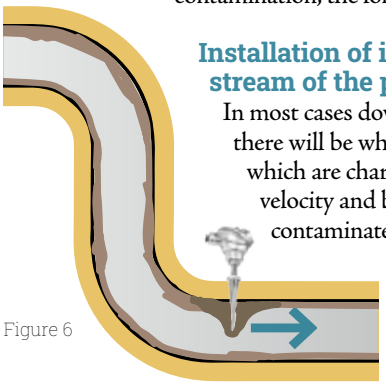


Figure 6

Installation of insert probe downstream of the pipe bend

In most cases downstream of the pipe bend, there will be what are termed "wakes", which are characterised by low flow velocity and backflow. In the case of contaminated fluids, there will also be a build-up of contamination in the wakes. If a sensor is installed in the wakes, problems can occur. See *Figure 6*.

The low velocity restricts the heat flow to the wall in the wake area, and the temperature difference between the fluid and the wall increases. In this case, when determining the pipe's temperature in order to calculate the degree of measurement error, we need to consider the axial heat flow along the pipe as well as the radial heat flow within the pipe. Low velocity around the protective tube will also reduce the convective heat flow to the protective tube and sheathed thermocouple. The contamination will therefore result in an increase in the measurement error.

If the temperature of the main flow changes, the low velocity in the wakes means that the temperature of the liquid in that area will adjust comparatively slowly to that of the main flow. The heat transfer coefficient between the liquid in the wakes and the protective tube will also drop as a result of the low flow velocity. So, there will be a reduction in the heat flow to the measurement location. Overall, this means that the response time will increase.

An installation involving an insert probe in the wakes both increases the measurement error and extends the response time compared to an installation outside this area. Furthermore, the contamination has a negative effect both on the measured value and on the response time, compared to the situation involving a clean liquid. Where possible, a measurement installation in the wakes should be avoided.

Installation of surface-mounted sensor downstream of the pipe bend

If we install a surface-mounted sensor in the wakes downstream of the pipe bend, we generally encounter the same disadvantages as with an insert probe positioned in the wakes. The measurement error increases and the response time is lengthened. In this case too, the contamination has a negative effect both on the measured value and on the response time. Where possible, an installation of this kind should be avoided.

Installation of an insert probe in the pipe bend

In *Figure 7*, the sensor has been positioned in the pipe bend itself and the narrow tip of the sensor is parallel with the flow upstream of the bend. In this case, there will be rather less contamination

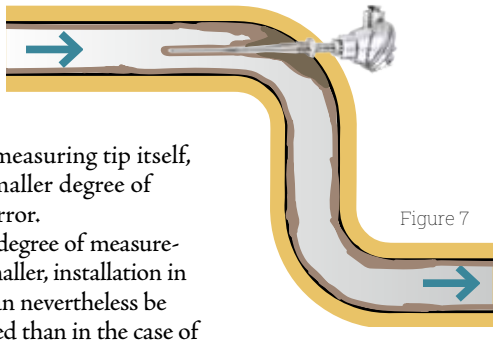


Figure 7

coating on the measuring tip itself, resulting in a smaller degree of measurement error.

Though the degree of measurement error is smaller, installation in the pipe bend can nevertheless be more complicated than in the case of the previous installations. Significant coatings may also occur at the sensor's mounting, and this will also affect the flow in the pipe and increase the flow resistance.

A long insert and a narrow sensor reduce the heat flow to the pipe wall, which also reduces the loss in the protective tube. The sensor must be designed to withstand the anticipated forces from the flow, which imposes requirements on inter alia the sensor's diameter and length. From a measurement technology perspective, this solution is often the preferred one. However, in many cases an installation in the bend is difficult to execute and, like all insert probes, it will result in a greater drop in pressure. The increased drop in pressure will in turn require additional pumping power.

Sensor positioning – a summary

Where possible, avoid installing the sensors in the wakes downstream of the pipe bend. This applies in equal measure to insert probes and surface-mounted sensors. However, there may be cases where there is no other option but to install a sensor in this area. You would then have to be aware of the measurement errors and increased response times such an installation will entail.

Unfortunately, there is no overall answer to the question of whether you should opt for an insert probe or a surface-mounted sensor. Both types of sensor have their advantages and disadvantages. You should opt for the type of sensor that is most advantageous for the requirements in question.

Installation of a sensor in the pipe bend where the sensor is parallel with the pipe upstream of the bend has many advantages, but also quite a few disadvantages. A long insert and a narrow sensor tip reduce the effect of contamination and result in a small degree of measurement error and short response time. One disadvantage is that the installation is comparatively complex. Other disadvantages are that the flow resistance is increased and contamination may accumulate at the mounting in the wall.

As stated above, all measurement installations have advantages and disadvantages. Unfortunately, there is no such thing as a "best measurement installation" that applies universally to all types of requirement. On the other hand, we can almost always identify an optimal installation for the requirements in question. Examples of such requirements are minimum measurement error, shortest response time and minimum flow resistance. ▮

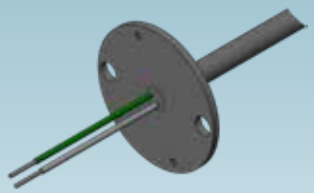
Dan Loyd,
Professor emeritus,
Linköping University.
dan.loyd@liu.se

Common connection options for **thermo-couples** and **resistance thermometers**

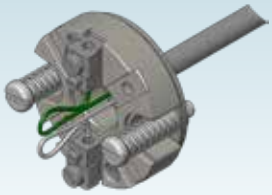
Connections are a critical part of your measurement chain and when choosing which one to use, it is important to consider not only the measurement uncertainty but also the accessibility, the surrounding environment and the ease of replacement. There is now a great variety of both connectors and casings, 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

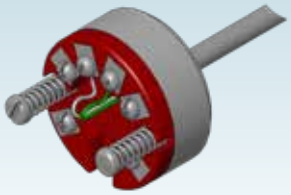
Pt100 cable with free wires



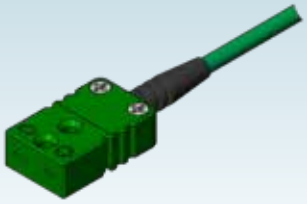
Measurement insert ready for mounting of a terminal head or transmitter (T/E or Pt100)



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



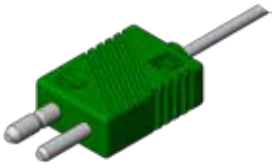
Measurement insert with transmitter (T/E or Pt100)



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

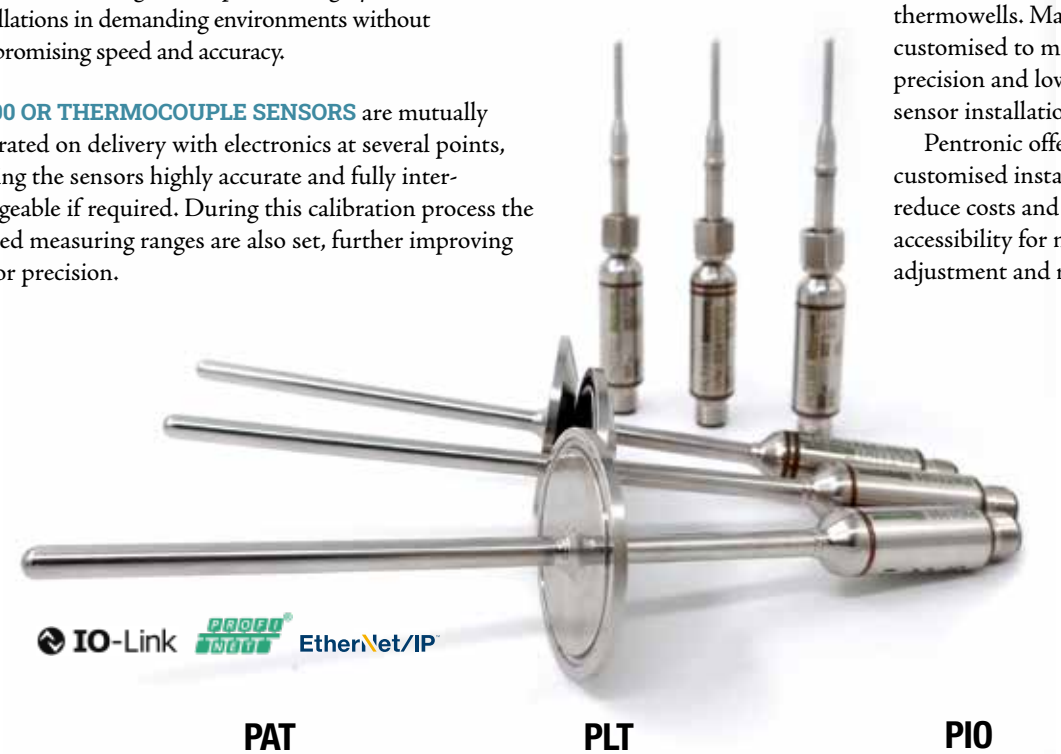
Digital **communication**

PENTRONICS' SERIES of integrated signal converters developed for industrial applications combines a flexible mechanical design with market-leading measurement accuracy at the system level. The modular configuration provides highly secure and reliable installations in demanding environments without compromising speed and accuracy.

PT100 OR THERMOCOUPLE SENSORS are mutually calibrated on delivery with electronics at several points, making the sensors highly accurate and fully inter-changeable if required. During this calibration process the desired measuring ranges are also set, further improving sensor precision.

The process connectors can be made according to a variety of designs to suit the application's requirements, for example for food safety, hygiene or pressure tightness. The standard range includes a number of specially designed weld-in bosses and thermowells. Many of these are also customised to maintain a high precision and low response time of the sensor installation.

Pentronic offers flexibly customised installation cabling to reduce costs and increase sensor accessibility for maintenance, adjustment and replacement.

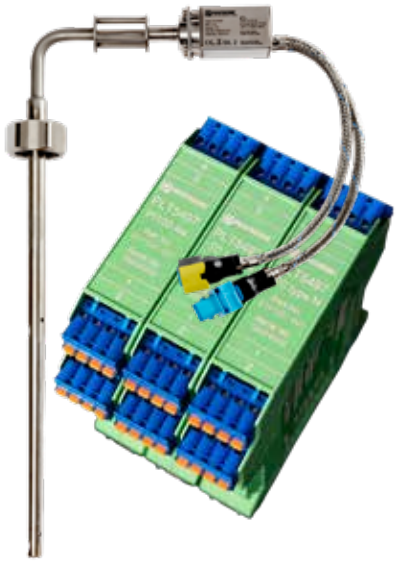


	PAT	PLT	PIO
Signal output	4...20mA	PLB® Bus	IO-Link
Probe tip	4w Pt100	4w Pt100	4w Pt100/Thermocouple
Process connections	Multiple options are available including advanced hygienic process connections, TC flanges and bayonet caps but the connections can also be designed with M12, miniature or standard process connectors. Another option is free wires.	Multiple options are available including advanced hygienic process connections, TC flanges and bayonet caps but the connections can also be designed with M12, miniature or standard process connectors. Another option is free wires.	Multiple options are available including advanced hygienic process connections, TC flanges and bayonet caps but the connections can also be designed with M12, miniature or standard process connectors. Another option is free wires.
Rec. max. process temp.	600 °C*	600 °C*	Pt100: 600 °C* Thermocouples: 1200 °C*
Rec. max. ambient temp.	80 °C	80 °C	80 °C
Recommendations	Highly versatile analogue sensors based on proven technology and communication.	Flexible digital systems for very high measurement accuracy. Recommended for installations with many measuring positions. Minimised cabling thanks to cost- and energy-efficient digital bus communication.	Digital and highly versatile system based on standardised communication. Very high accuracy allows for integration into existing systems.
Configuration**	Pentronic UPI1611***	Pentronic UPI1611***	IO-Link standard, several alternatives available.
Accessories	Customised cabling.	Gateway for communication Profinet, EthernetIP.	Customised cabling.

**Depending on the requirements for measurement accuracy, mechanical design and the signal converter's configuration.*
*** All integrated sensors are delivered configured to specifications.*
**** UPI1611 configuration tool for PAT- and PLT systems.*

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 with 1, 2 or 3 connected sensors, alternatively: DIN rail-mounted signal converter with up to 4 channels
- Inputs for Pt100/1000 or thermocouple sensors.
- (types: K, N, ...)
- Gateway connects to PROFIBUS DP/PROFIsafe
  Gateway for IECEx/ATEX zone 1 based on PROFINET over APL – launching in 2023
- Redundancy that supports excellent availability

The PLB 5000 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

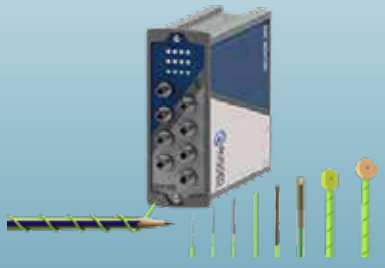
Flow meters

Glass flow meters (GFM)

Moisture meters and NIR equipment

Transmitters

Calibration equipment



Fibre optics

Data loggers

Contactless IR pyrometers

Faulty connections of thermocouples and Pt100

Keep this in mind when connecting thermocouples.

Circuit break (open circuit)

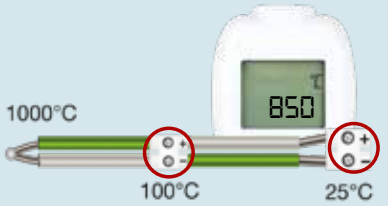
A sensor wire has become detached, loosened or is in poor contact with the instrument. The instrument triggers an alarm, e.g. by displaying the word "Open".

Reversed polarity of entire measuring circuit

If the polarity has been reversed, the instrument will operate "in reverse". A temperature increase will be recorded as a temperature decrease.

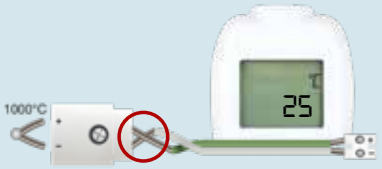
Double reversed polarity

If the polarity of the extension cable has been reversed at both ends, the temperature at the ends will affect the output signal. The reading will be the temperature at the measuring junction minus twice the temperature difference between the terminal head and the reference junction. Keep in mind that if a temperature controller having a set-point value of 1000 °C is connected, the power will be stepped up, thereby giving a true value approximately 150 °C higher than the set-point value. However, the instrument will still display a reading of 1000 °C.



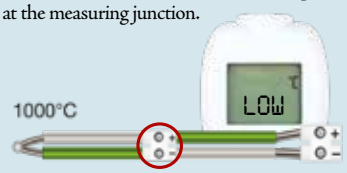
Short circuit

If the insulation wears off and the wires are short circuited, a measuring junction is created. The instrument will then display the temperature at the short-circuit point instead of at the probe tip.



Reversed polarity within the measuring circuit

The extension cable must have the same polarity as the thermocouple wires. If the polarity of the thermocouple is reversed, opposing voltages occur. The reading obtained will then be twice the temperature in the terminal head minus the temperature at the measuring junction.



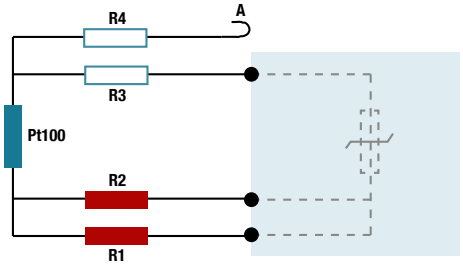
Keep these in mind when connecting Pt100s to avoid misleading measurement results

4-wire Pt100 to 3-wire indicator

Be careful of false 4-wire connections. It can be tempting to connect two wires in the same terminal of an instrument built for 3-wire measurement.

The result will be a 50 percent difference in resistance between the different branches of the 3-wire indicator, where equal resistance is necessary for zero error. See the adjacent figure for the correct way to connect a 4-wire Pt100.

With a 10 m 4 x 0.25 mm^2 extension cable the measurement error is approx. 0.9 °C.



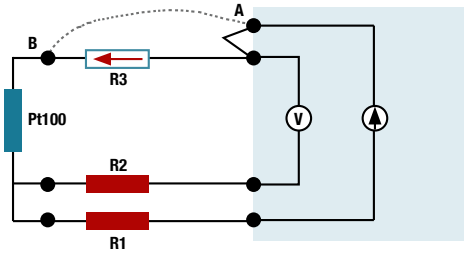
The correct connection of a 4-wire Pt100 to a 3-wire indicator. One of the wires (any will do) must be left unconnected. See A.

3-wire Pt100 to a 4-wire indicator

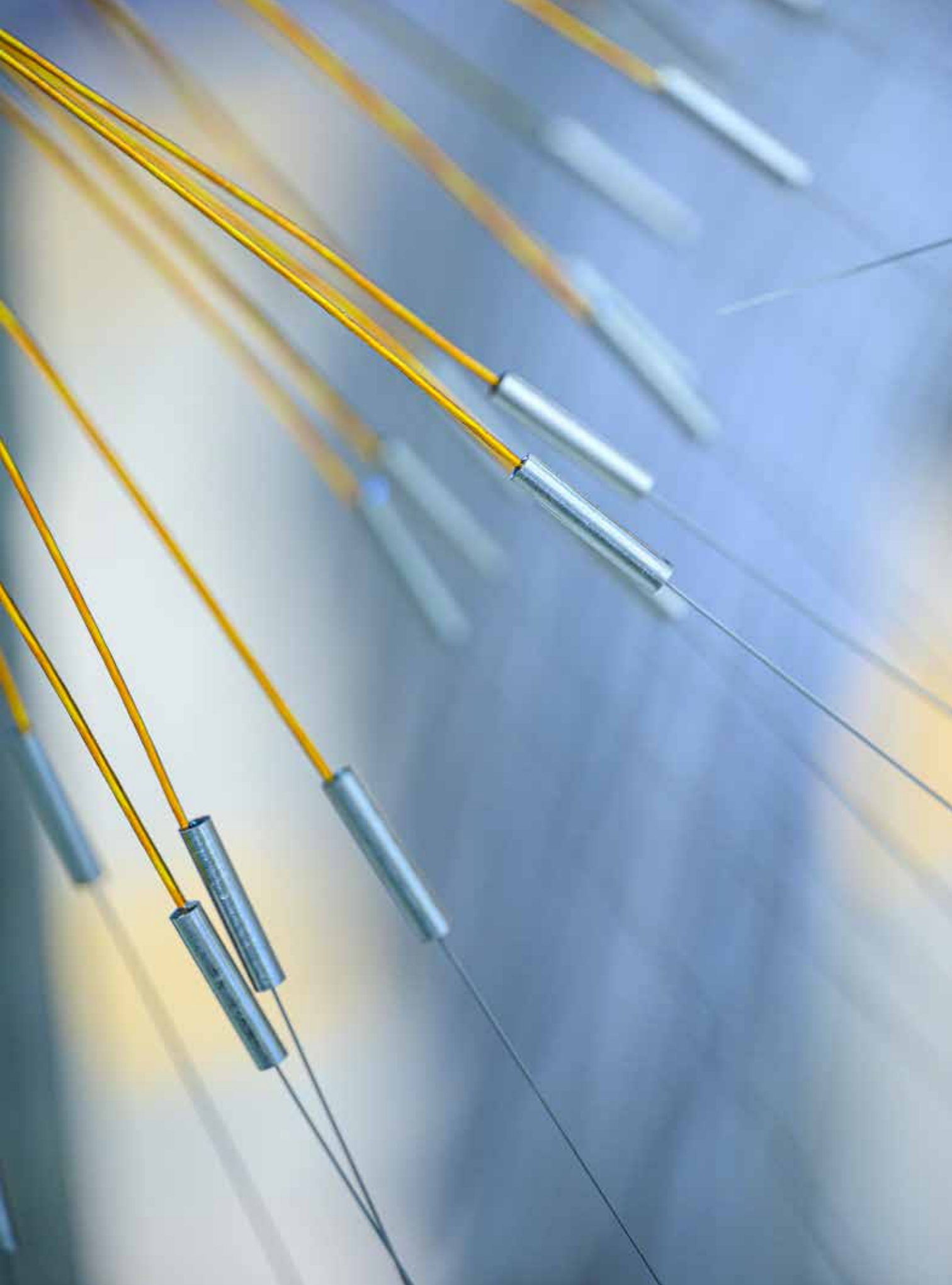
A Pt 100 with 3 wires plus an instrument for 4-wire connection. The changeover from 4 wires to 3 is done as close to the sensor as possible. In the adjacent figure this is done at B, as shown by the dotted line.

If you connect at A instead, the measuring current must pass through the wire with R3. The indicator then shows the resistance for the Pt100 plus the resistance R3. The error can then be approx. 1.8 °C (for a 10 m 3 x 0.25 mm^2 wire).

When the connection is correctly made at B, the measuring current encounters less resistance en route to the Pt100. For a short process sensor, the increase can lead to a measurement error of approx. 0.1 °C.



The correct connection of a 3-wire Pt100 to a 4-wire indicator involves transitioning to the 3-wire configuration as close to the sensor as possible to achieve the lowest measurement error. Connecting at B gives a lower error reading than connecting at A. The reason is that the power generating loop must be separated from the voltmeter circuit (R3) except in the Pt100 sensor itself.



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)	Minimum approved insulation (MΩ)
100	100

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

Thermocouples:

- Do not exceed the resistance thermometer's 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:

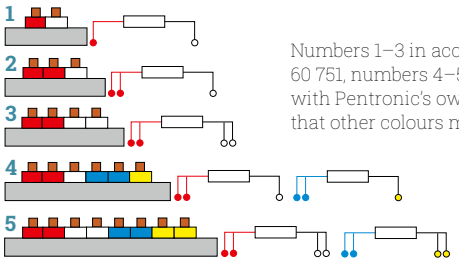
- With a multimeter, measure the resistance between the conductors.
- The resistance on a healthy sensor should be 0 Ω.
- An open input indicates a broken circuit
- Using an insulation tester, measure the insulation between the inner conductor and the outer sheath (see the extract from IEC 61515:2016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

Outer diameter D (mm)	Test voltage (Vdc)	Minimum approved insulation (MΩ)
0.5 < D ≤ 1.6	100	20
1.6 < D	50 to 100	1000

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

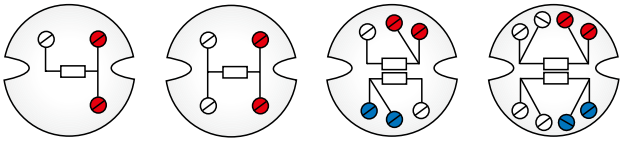
Contact us if you are unsure about the operation of your temperature sensor. Want to know more about temperature sensors?
Visit www.pentronic.se
Download your test certificate at www.pentronic.se

Extension cable for Pt100s



Numbers 1–3 in accordance with IEC 60 751, numbers 4–5 in accordance with Pentronic's own standard. Note that other colours may be used.

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 AlO3 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	Working range in °C	Atmosphere
E		-200 - 900	Good in oxidising environments
J		-200 - 760	Not in oxidising environments or acids
K		-200 - 1200	Good in oxidising air environments
N		0 - 1300	Like K but standardised to be better over 200 °C
T		-200 - 370	Not in oxidising environments
S/R		0 - 1480	Ceramic protection tubes, all environments
B		0 - 1700	Ceramic protection tubes, all environments
C/D		0 - 2315	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	90	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
SILICON	-60	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
POLYIMIDE	-265	260	6101000	NA	5	5	5	4	4
GLASS FIBRE	NA	510	6102000	NA	1	3	3	5	5
CERAMIC FIBRE	NA	1200	6101000	NA	2	3	2	5	5

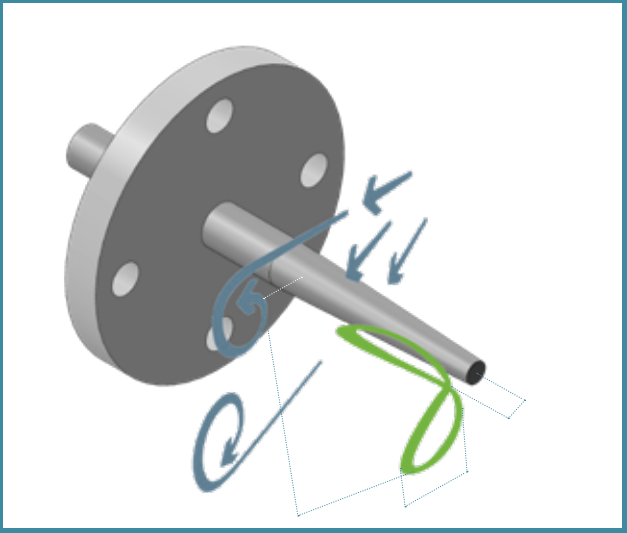
1– 5 where 1 is worst and 5 is best. Note that the table describes generalised properties of the insulation material; the properties of specific cables may differ. When selecting a cable always consult the relevant data sheet for the precise specifications.

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

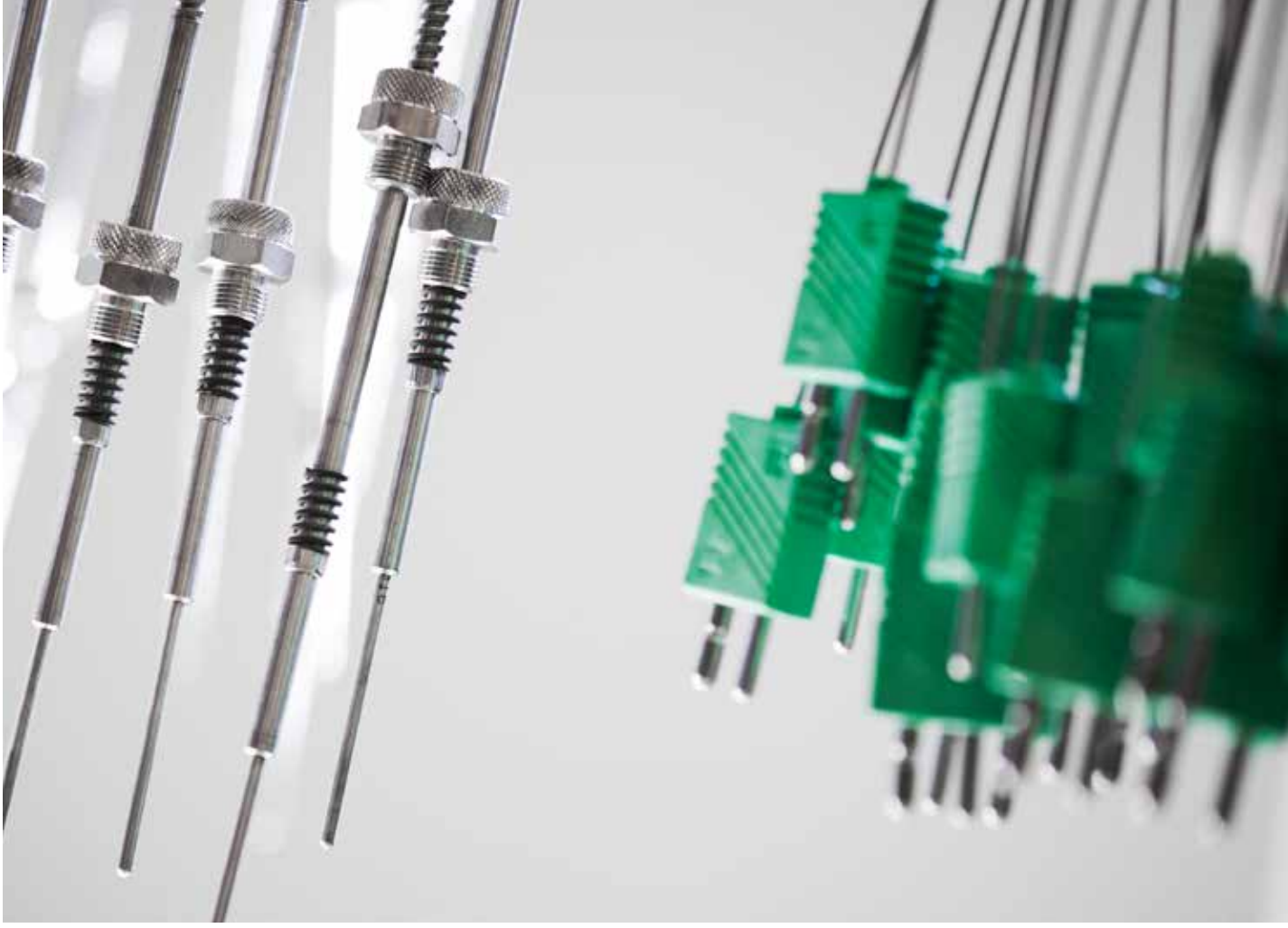
* Inconel 600 is designed for safe use over a very broad temperature range and is used as a sheath material in high quality sheathed thermocouples. Properly designed, an Inconel 600 sheathed thermocouple can withstand working temperatures up to 1150 °C. See further in the table below.



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.



Dimensions and **resistance** of various thermocouple wires

Dimensions			Conductor resistance in ohms per metre of wire					
AWG	Diam. mm	Area mm²	K	N	J	T	S	Cu/Cu
18	1.02	0.823	1.2	1.6	0.86	00	0.4	0.04
20	0.81	0.519	1.9	2.6	1.2	1.0	0.6	0.07
22	0.64	0.324	3.1	4.1	1.9	1.5	0.9	0.11
23	0.57	0.259	3.9	5.1	2.3	2.0	1.2	0.13
24	0.51	0.205	4.9	6.5	3.0	2.5	1.5	0.17
25	0.45	0.162	6.2	8.2	3.7	3.1	1.8	0.21
26	0.40	0.128	7.8	10.4	4.7	3.9	2.3	0.27
28	0.32	0.080	11.8	16.5	7.5	6.3	3.7	0.43
30	0.25	0.051	19.8	26.2	12.0	10.0	5.8	0.68
32	0.20	0.032	30.9	41.0	18.8	15.6	9.3	1.08
34	0.16	0.020	49.7	66.1	30.2	25.2	14.8	1.71
36	0.13	0.013	79.0	105.0	48.1	40.1	23.5	2.72
38	0.10	0.008	123.7	164.0	75.3	62.5	37.3	4.33
40	0.08	0.005	205.4	273.1	124.1	103.8	59.3	6.88

AWG = American wire gauge.

The conductor resistance in ohms per metre of wire means the total resistance of 1 metre of both wires in a single pair of wires. For Pt100 wire, the total resistance of 1 metre of two wires is given, which also corresponds to the resistance of 2 metres of one wire.

The stated measurements are rounded off and should be considered as guidelines. Deviations may occur.

Compensation material – denoted by the letter C, e.g. KC – has a different resistance than that of the corresponding thermocouple material.

Cu/Cu stands for copper in both wires and has been included for comparison.

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, 780900.

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.

www.pentronic.se/
products

Sales

Per Bäckström

Sales Engineer /
Technical Expert

+46 (0)490 25 85 52
+46 (0)70 543 02 84
per.backstrom@pentronic.se

Glass flow meters
Ex/ATEX applications
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Contact-free measurement
Flow measurement

Christophe Zaninotti

Sales Engineer /
Area Sales Manager

+46 (0)490 25 85 18
+46 (0)70 441 60 07
christophe.zaninotti@pentronic.se

Research & development
Life Science/ pharmaceuticals
Vehicles & engines

Jonas Bertilsson

Sales Engineer /
Technical Expert

+46 (0)490 25 85 51
+46 (0)70 542 79 97
jonas.bertilsson@pentronic.se

Equipment for high-temperature applications
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Mechanical adaptation

Michael Steiner

Sales Engineer /
Area Sales Manager

+46 (0)490 25 85 07
+46 (0)70 352 54 51
michael.steiner@pentronic.se

Food processing
Power generation

Lars Grönlund

Sales Engineer /
Technical Expert

+46 (0)490 25 85 21
+46 (0)70 672 28 52
lars.gronlund@pentronic.se

Calibration & calibration equipment
Hygienic applications
Accredited services

Morgan Norring

Sales Engineer /
Area Sales Manager

+46 (0)70 255 83 63
morgan.norring@pentronic.se

Steel & metal industry
District heating plants
Chemical industry

Jens Jupiter

Inside Sales

+46 (0)490 25 85 93
+46 (0)70 360 85 93
jens.jupiter@pentronic.se

Sebastian Rosander

Inside Sales

+46 (0)490 25 85 24
sebastian.rosander@pentronic.se

Viktor Svahn

Inside Sales

+46 (0)490 25 85 12
+46 (0)72 455 15 45
viktor.svahn@pentronic.se

Per Andersson

Service technician

+46 (0)70 208 91 98
per.andersson@pentronic.se

Accredited laboratory

www.pentronic.se/
contact

Andreas Holm

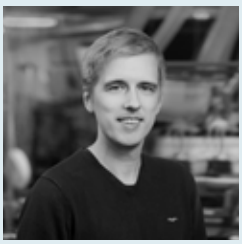
Laboratory Manager

+46 (0)490 25 85 22
andreas.holm@pentronic.se

Karoline Haneck

Laboratory Engineer

+46 (0)490 25 85 23
karoline.haneck@pentronic.se



Nicklas Holm

Laboratory Technician

+46 (0)490 25 85 28
nicklas.holm@pentronic.se

Emma Rosenblad

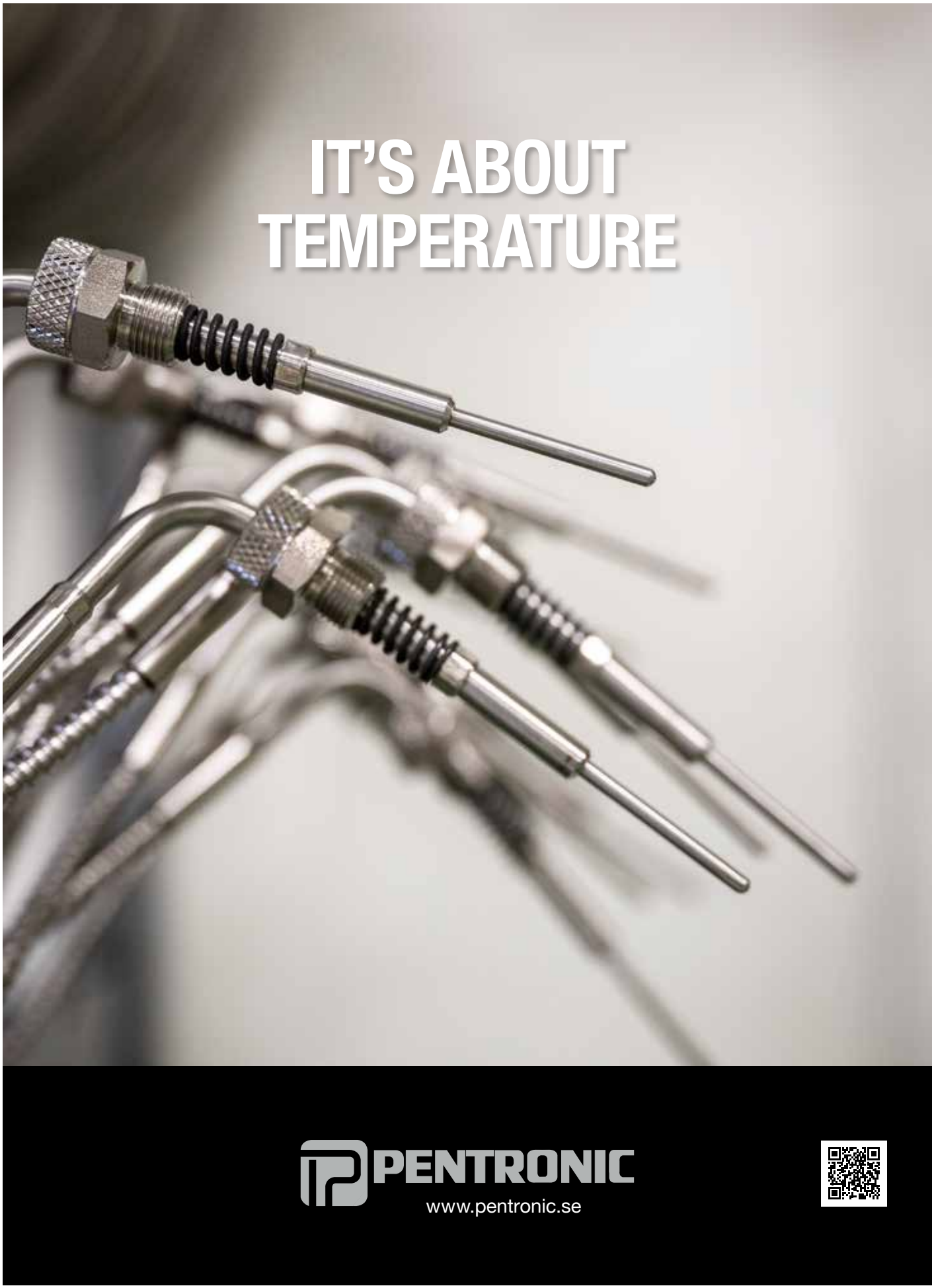
Laboratory Technician

+46 (0)70 245 58 50
emma.rosenblad@pentronic.se

Jakob Almqvist

Laboratory Technician

+46 (0)70 550 12 81
jacob.almqvist@pentronic.se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