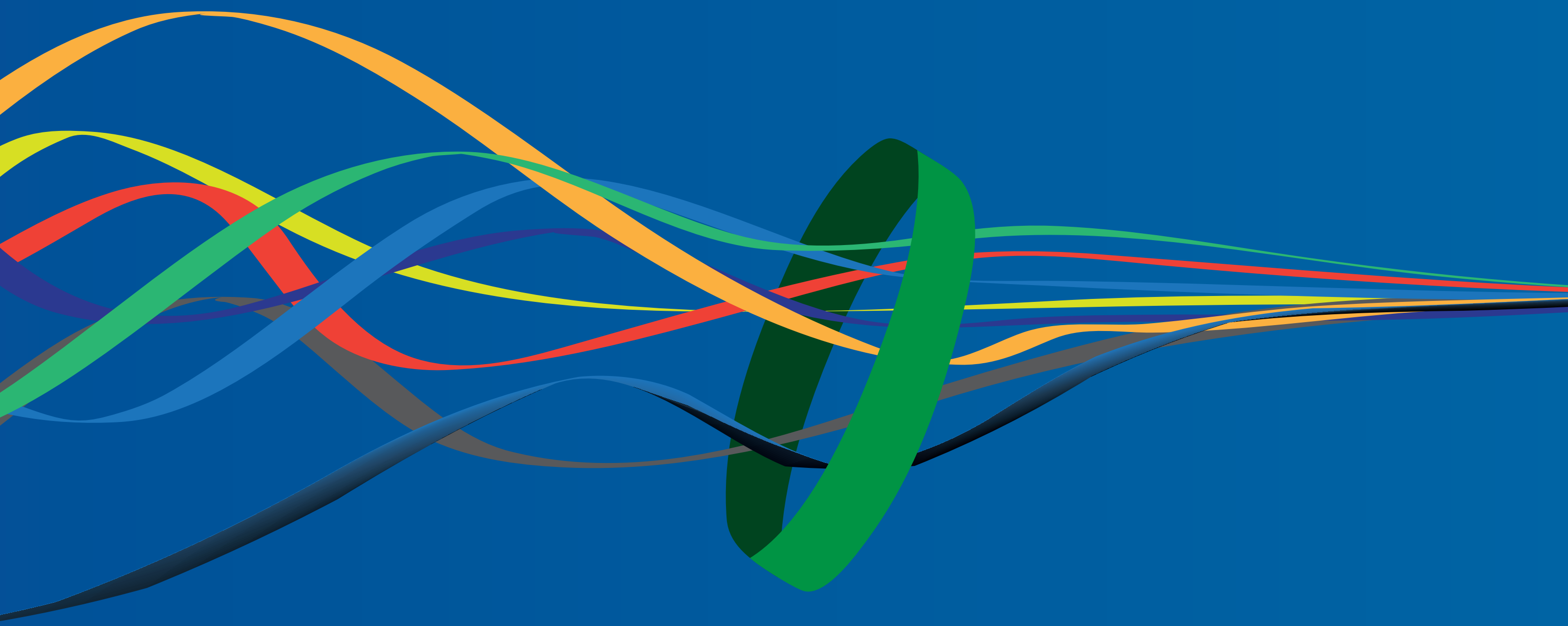
# iTEC

Intelligent Thermal Error Compensation

– PLUG & PLAY SYSTEM –






THE WORLD'S FIRST
REAL-TIME
THERMAL
COMPENSATION
SYSTEM

# WHY THE CUSTOMER NEEDS iTEC

## THERMAL ERRORS FACED BY MANUFACTURERS.

There are many reasons why a customer should implement the iTEC system.

- Accuracy Errors
- Datum (thermal) drifting
- Jobs vary in size
- Mismatch between finishing tools
- Machine bending and distortion
- Unable to maintain tight tolerances throughout the day
- Warm up times impact on productivity
- Interruptions to the machine
- Lack of climate control in factories.
- Temperature changes impact on machines accuracy
- Pressure on productivity to increase products
- Greater desire for empowerment
- Better return on capital investment
- Works with automated robotic loading systems

# WHAT CAUSES THESE PROBLEMS?

There are 3 primary reasons why thermal drift probems occur.

## RADIATED

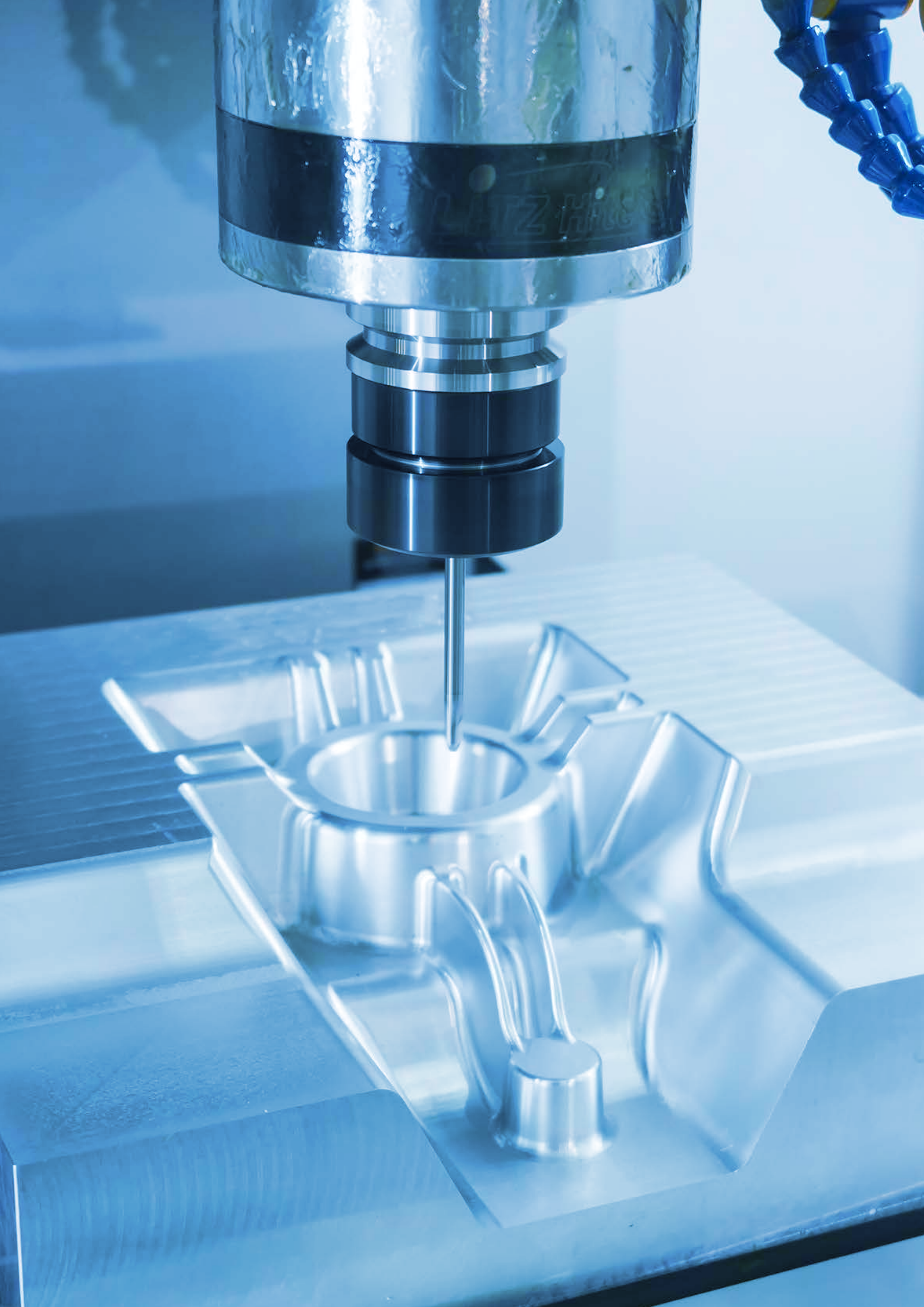
Infrared workshop heating
Direct sunlight striking the machine

## ENVIRONMENTAL

Workshop heating
Use of doors (Creating draughts)
Direct sunlight heating the air
Heat generated by other machines in the vicinity
Heat loss to the air from the machine itself
Heat generated by the cutting process.
Accumulation of swarf

## INTERNAL

Friction in spindle bearings
Heat generated by spindle and axis drive motors
Heat generated by viscous friction in  hydraulic and coolant systems
Heat generated by transmission systems (gearboxes, belts, etc.)
Heat generated by friction in seals



# CAUSES OF THERMAL DRIFT

Manufacturers who must consistently produce accurate and precise parts need to overcome and work with thermal expansion in particular with modern fast CNC machine tools where increasingly high accelerations, feed rates and high spindle speeds cause heating of the machine frame and the drive mechanisms.

Thermal growth can be caused by cutting conditions and the ambient conditions on the shop floor which can vary dramatically due to daily and seasonal temperature conditions as most workplace environments are not usually environmentally controlled.

On a machine tool one of the first considerations in dealing with heat which is generated in the spindle by the bearings, belts, spindle motor and the slide ways.

For example, In a C Frame machine structure this heat migrates into the casting and creates expansion in the Y and Z Axes. As the Y Axis expands due to heat, the column of the machine tends to lean backward and down, the Y Axis and Z Axis positions are affected. As the machine expands the effects of the thermal expansion forces the operator to continuously chase tolerances or mismatches in surface finish.

The heating and cooling process continues throughout the shift as the machine sits idle during set-up, tool change-overs, lunch breaks etc.

One costly way to eliminate as much heat as possible can be achieved by using a chiller to cool the spindle. The chiller will maintain a consistent temperature range within the spindle cartridge, even in extreme duty cycles, to within a few degrees of ambient.

Some machine tool builders fit hollow core ballscrews with refrigerant flowing through the centre of the ballscrews to prevent elongation of the ballscrews.

Another source of thermal expansion is the heat generated at the ballscrews causing expansion in the X, Y and Z Axes This thermal drift can cause changes in workpiece length typically 100um/m in 20 minutes. Feeding at 10m/min the ball screw temperature can increase from 25 degrees to 40 degrees very quickly.

The iTEC System comprises a mapped survey of all of the machine heat sources, multiple heat sensors connected to a high speed mini computer which transmits offset data to the machine controller in real time to adjust and compensate all axes ensuring highly accurate, repeatable and good quality parts from the beginning until the end of shift regardless of either ambient condition changes, tool breakages or stoppages for whatever reason.

# WHAT IS iTEC?

Until now machine tools have not been able to reliably position accurately and with repeatable results.

Attempts have been made to compensate the machine's geometric errors with so called volumetric compensation, unsuccessfully due to thermal errors.

One solution made to compensate for thermal growth errors is to try and PREDICT the problem.

THIS IS TOTALLY UNSUCCESSFUL.

There is no ability to predict how the machine tool is used by the end user.

Either by trying to predict what is machined, how it is machined, where it is machined or how fast it is machined or on what machine it is machined or even how the machine reacts to ambient or generic temperature.
You cannot predict the future errors, whether it's ambient temperature or machine induced temperature errors.

... UNTIL NOW.

The missing link in obtaining repeatable, accurate machining, all day, every day right from starting the machine in the morning to lights out at night has only been solved by iTEC.

iTEC does not try to predict errors because prediction does not work.

To succeed, the iTEC software calculates the errors present in real time, from real time thermal feedback, to give true compensation values to correct the tool point error on your machine tool.

Only this system works no matter how you use your machine tool, or when you start or stop machining, no matter what you machine or how you machine your parts, whatever the factory temperature.
You can now confidently probe parts on your machine to ensure accurate, repeatable and quality parts are produced all day, every day.

Be sure of getting the part you programmed correct every time and better than you could have imagined, reduce your costs by making your machine tool repeatable so you can produce better quality, more accurate parts with less scrap.

The iTEC system **compensates for all thermal error sources** that affect positioning accuracy throughout the **entire volume of the machine**. It is a full **five-axis** seamless and **secure compensation** applied by **one single algorithm.**

# iTEC STRUCTURE

The iTEC is based on a physics model of the machine and machining process and has been tested extensively on many machines.

It eliminates the need for warm up cycles either at the beginning of a shift or after a stoppage of any kind or duration.

The AI predictive method of dealing with thermal expansion whilst interesting, uses algorithms to compensate for thermal expansion based on machine design theories. This doesn't work because the assumption is that the machine tool heats and cools the same way, every time, in every condition under all duty cycles.

It is not physics based but uses mathematical formula to lump together data from different parts of the machine tool.

Furthermore what it has learnt is individual machine specific and cannot be transferred to other machines.

This is difficult if you need to compensate for environmental and machine generated effects.

AI can learn a false solution as training can be affected by both local and nearby electronic noise , whilst it might work for one situation it does not extrapolate in the same way as physics based systems would extrapolate.

Predictive compensation cannot distinguish between ambient heat sources such as lights, windows or seasonal variations and the spindle or motors. There is no feedback to allow you to know if the correct compensation will be applied. To ensure that the correct compensation is to be applied you MUST close the loop (from theory to practical) therefore testing the new calculated compensation, this means the machine must be used to measure an artefact by probe/displacement comparison or have a laser setup to ensure the correct position or some other method of physical verification. While the machine is doing this it is not cutting and therefore out of production. This must be done on each and every machine on a regular basis as ambient temperature and machine conditions change frequently (spindle bearings, ballscrew tension, thrust bearings etc). This is a huge loss of production and expensively time consuming.

iTEC has none of these drawbacks.

# Plug & Play

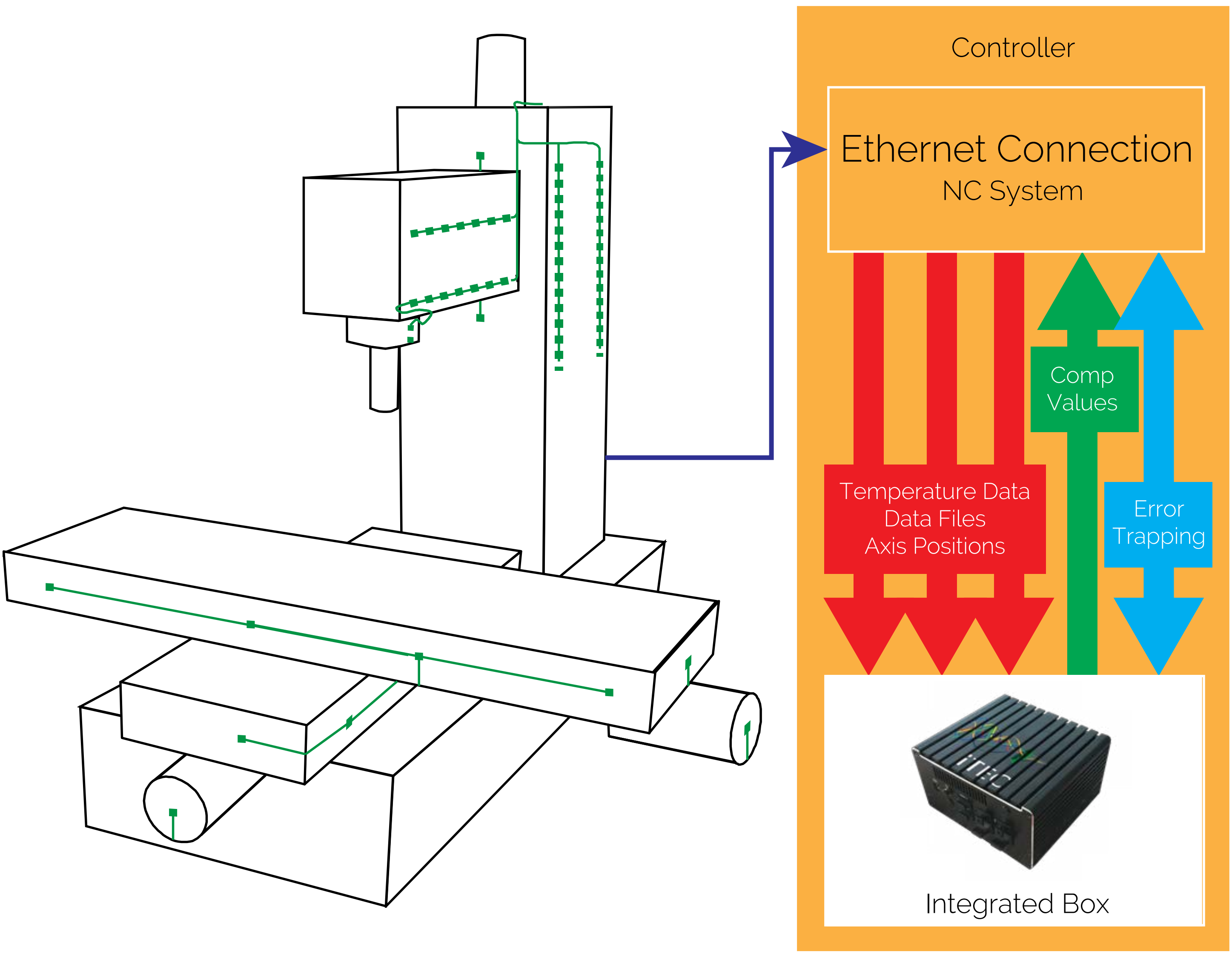
## Install and walk away

## iTEC INTEGRATED BOX SCHEMATIC AND SENSOR LOCATIONS

Sensors can be **applied discretely**, or in strips.

**Sensors have low profile**, allowing them to be applied in confined areas.

A **small cable** is required to carry the signal back in real time to the iTEC system.



# THE MAIN BENEFITS OF iTEC

| | | |
|---|---|---|
| **Eliminates** issues faced by **temperature changes** on machines | **Flexible programming** philosophy means that a **machine-specific thermal model** can be implemented during the integration process | Thermal Compensation values are calculated in **real-time** |
| Values are completely **position dependent** to enable **compensation for machine bending and distortion** | **Empowers customers** to achieve greater production | Model is written in a basic notation in **ASCII format** |
| The thermal error is resolved into the **calculated linear effect in the Cartesian axis** coordinate frame | Performs **a single heating and cooling cycle** whilst logging movements and temperatures | Compare modeled with actual movements and **optimise thermal model** |
| Identifies areas of **heat build-up and can be** tested with a **random duty cycle** | Applies temperature sensors to **structural elements** | Can be programmed with **any compensation model** |
| Can have **any number of temperature sensors** to achieve desired outcomes | Works with **4 & 5 Axis Tables** and **Robotic or Automatic Loading Systems** | **Real time, Plug and Play solution** |

**iTEC eliminates the need for machine warm-up cycles**, saving the user lost production hours, reduces energy costs, workforce hours, material wastage

iTEC **compensates all axes** simultaneously

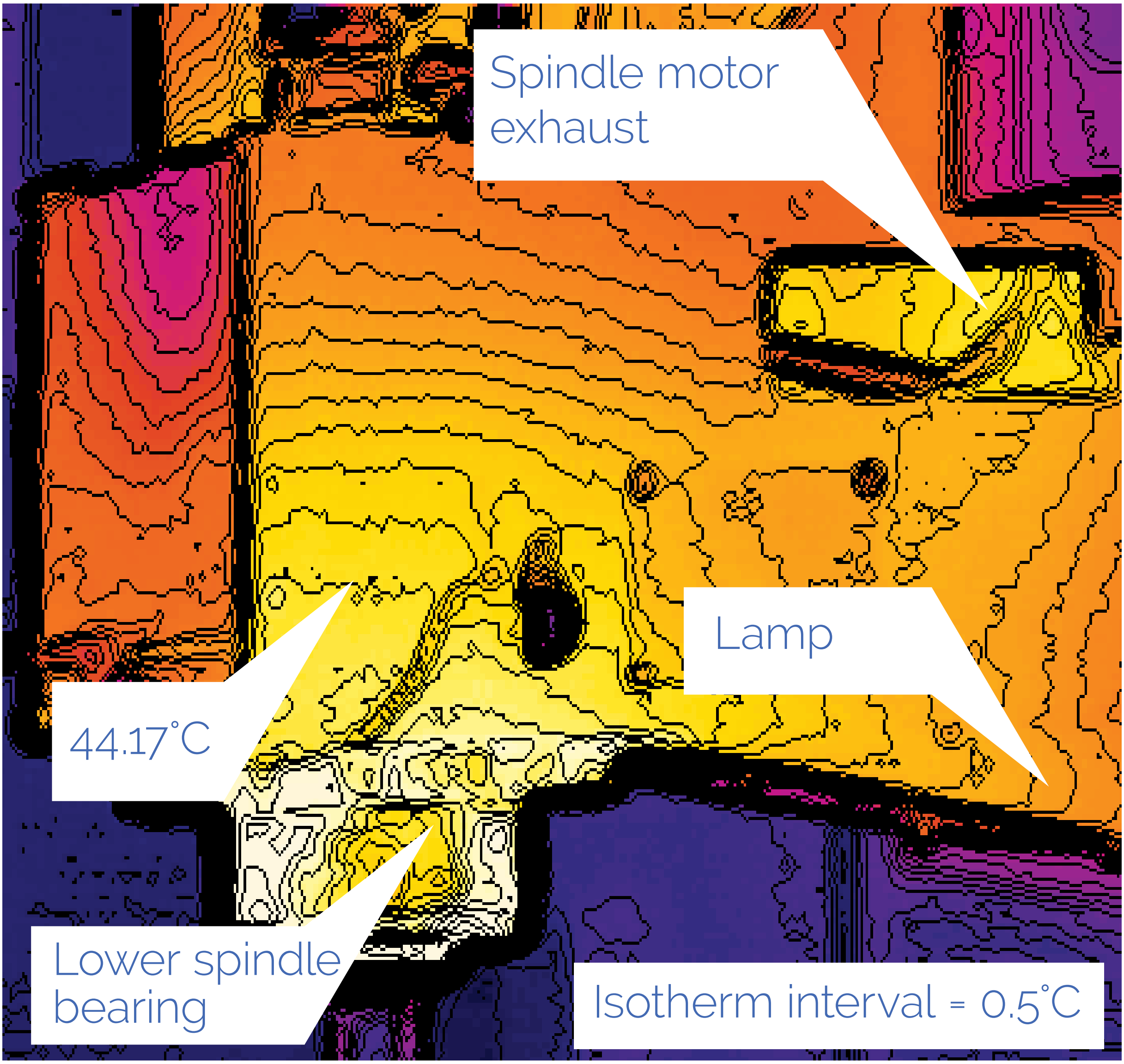
**No need to reset for changed machine conditions** such as; Changed Spindle Motor, Changed Ball Screw Bearings, Ambient Machine Position

**Plug and Play**
No need to individually set up for each machine

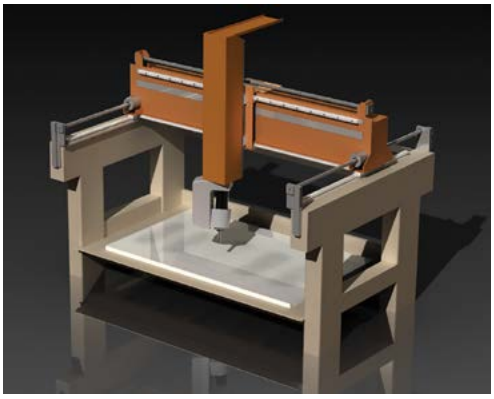
**The World's First Real-Time Thermal Compensation System**

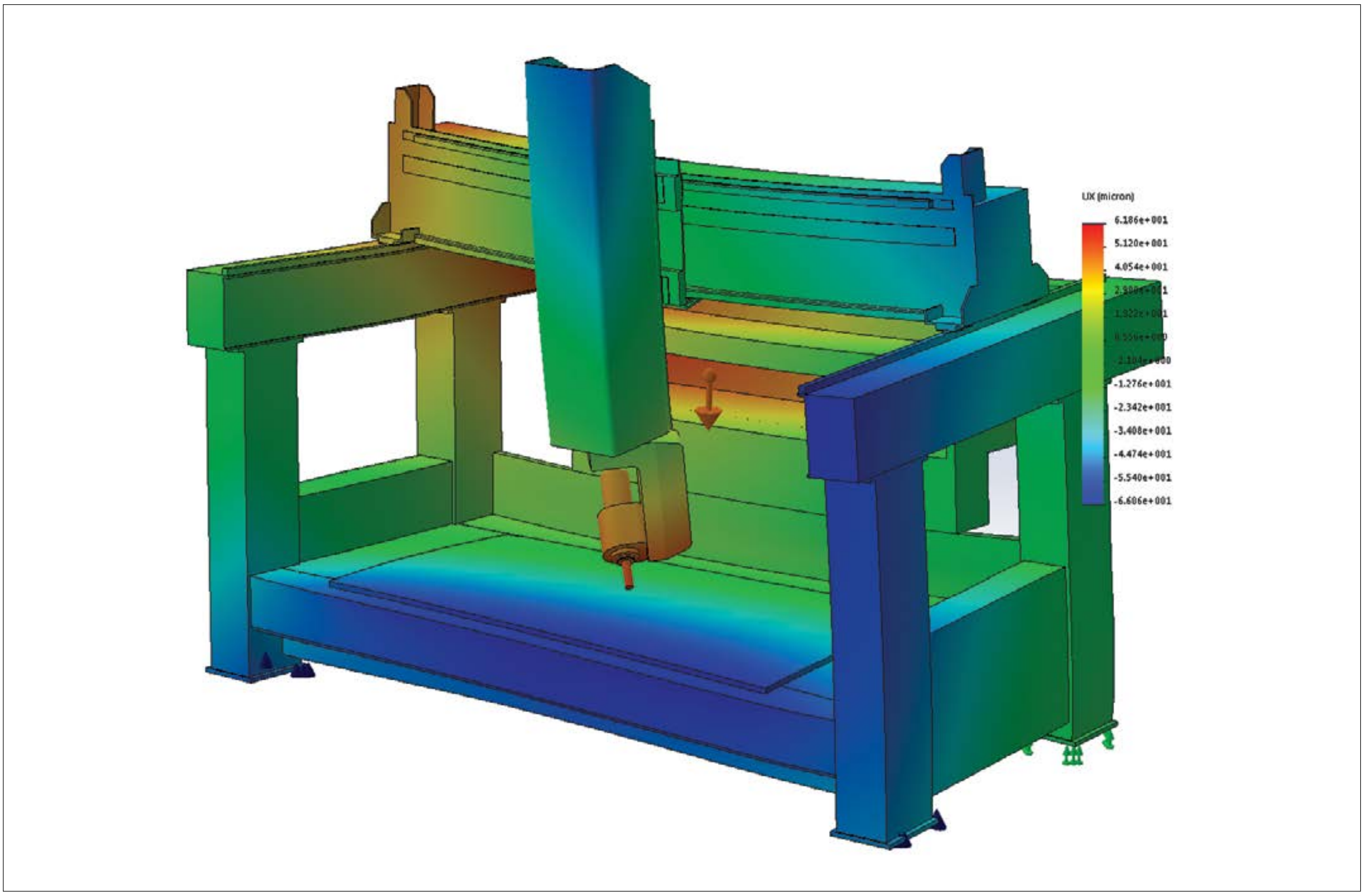

VOP60

# THERMAL IMAGING USED TO IDENTIFY HEAT BUILD-UP



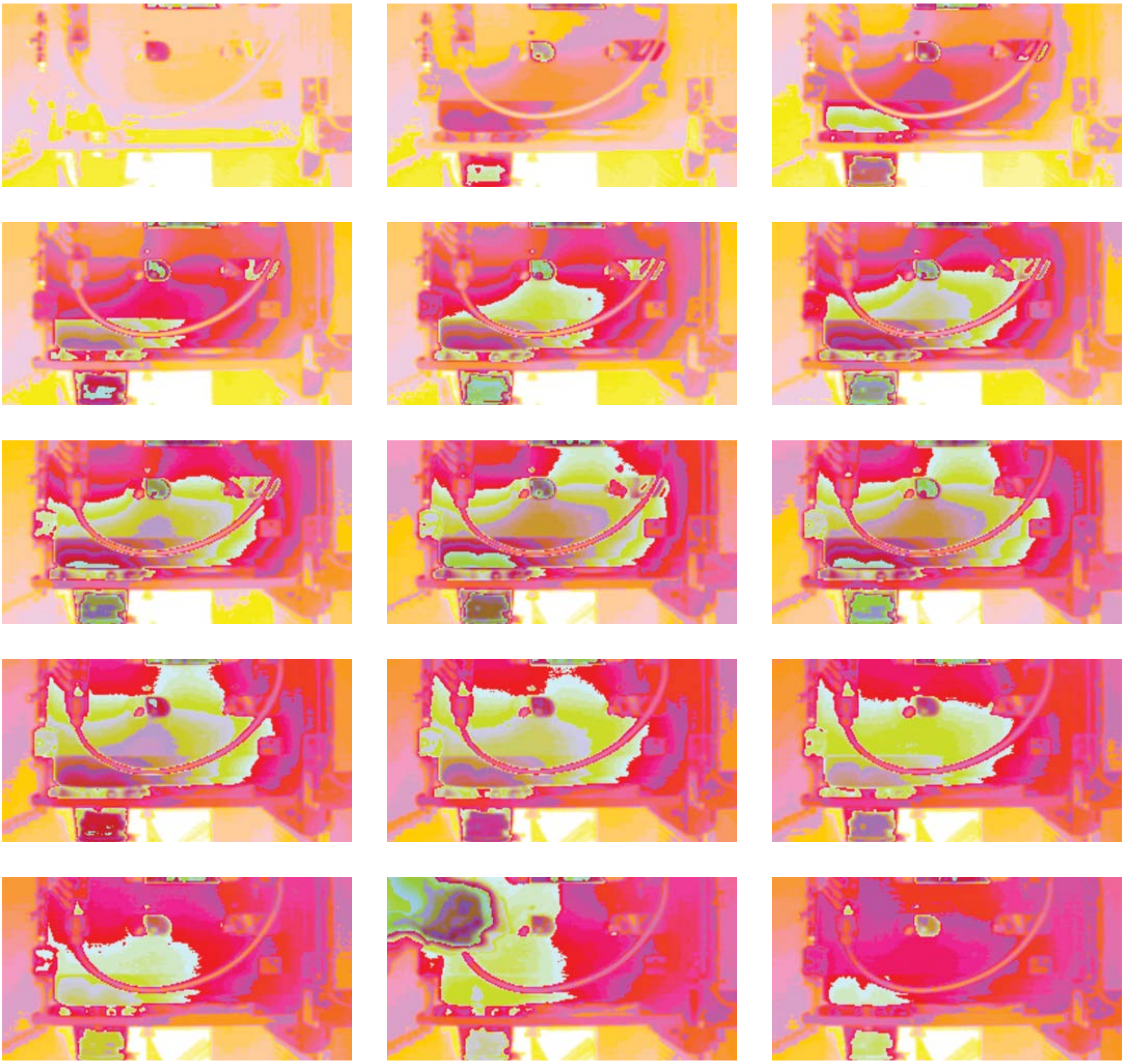
# SIMULATING MACHINE DISTORTION





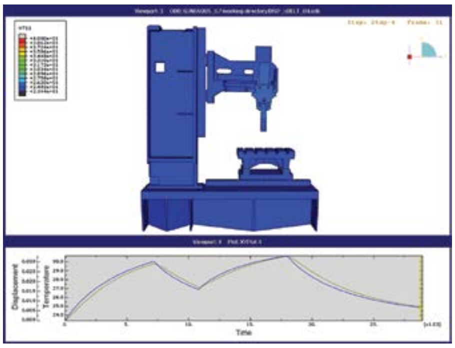
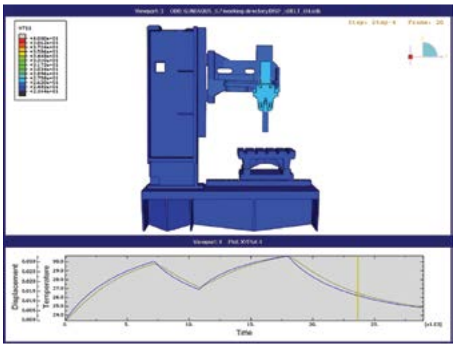
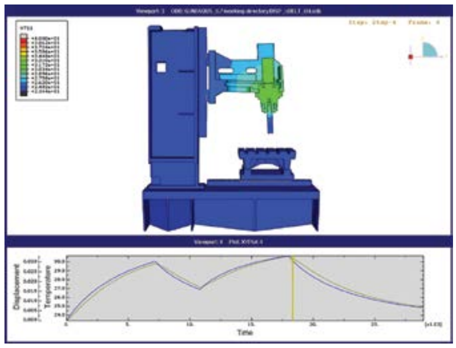
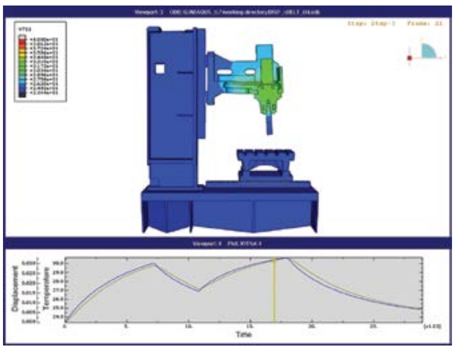
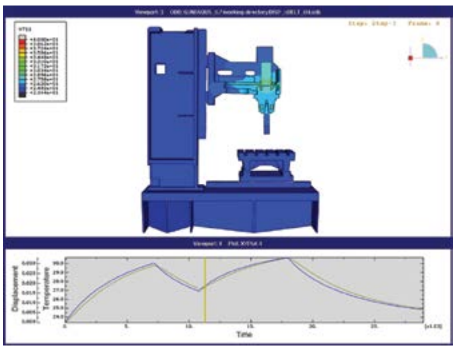
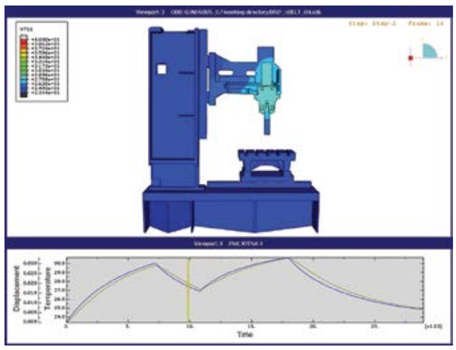
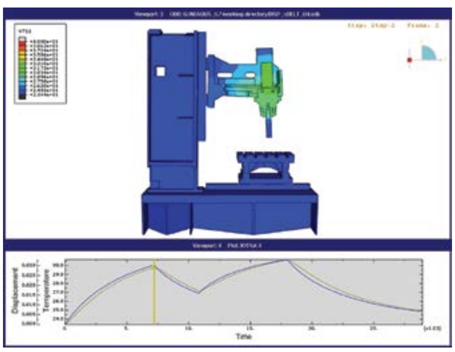
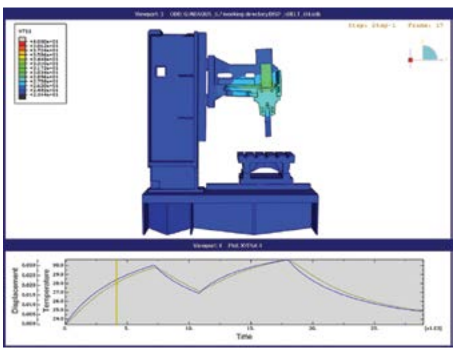
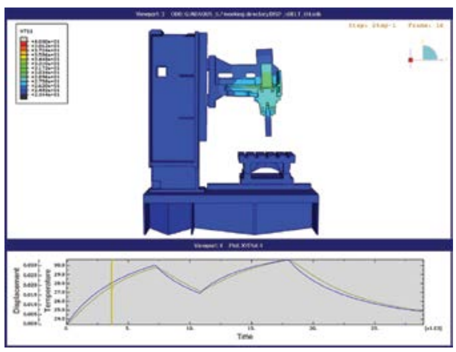
# SPINDLE HEAT THERMAL VIEW

Video stills of a spindle heat test. Visit www.dapatech.com to view the video



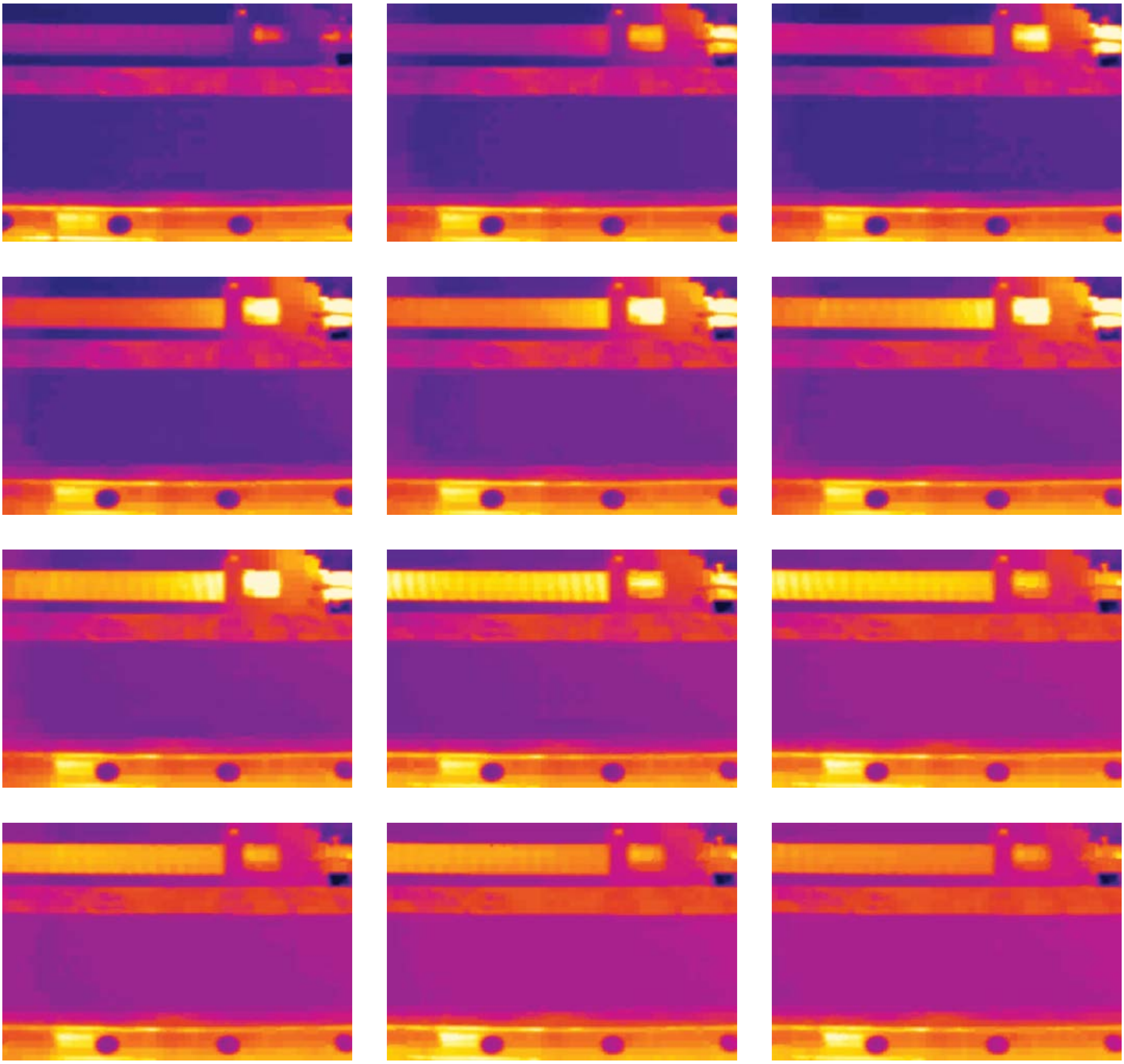
# SPINDLE HEATING THERMAL EFFECT

Video stills of a spindle heating thermal effect simulation. Visit www.dapatech.com to view the video

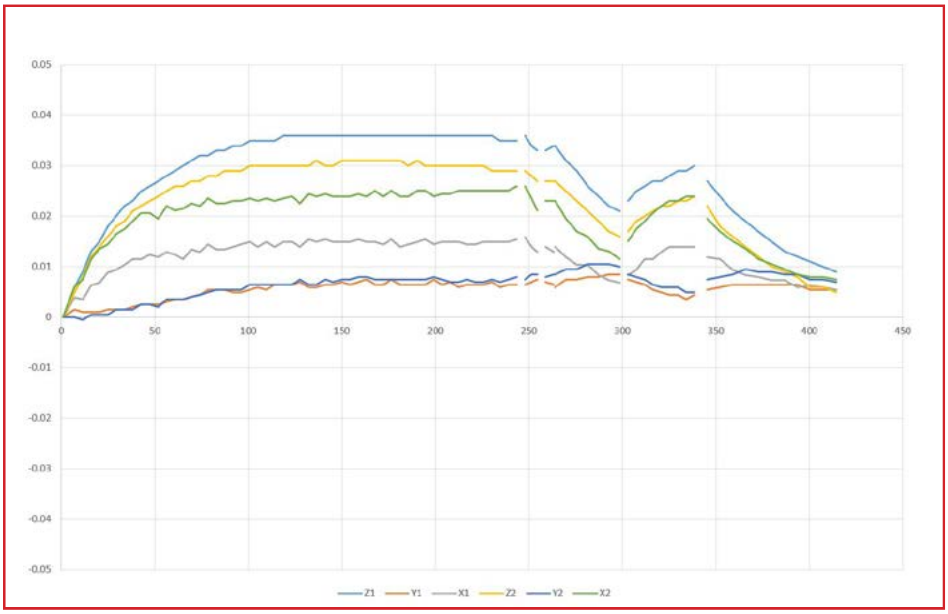
# SLIDE WAY & BALL SCREW THERMAL VIEW

Video stills of a ballscrew thermal view test. Visit www.dapatech.com to view the video



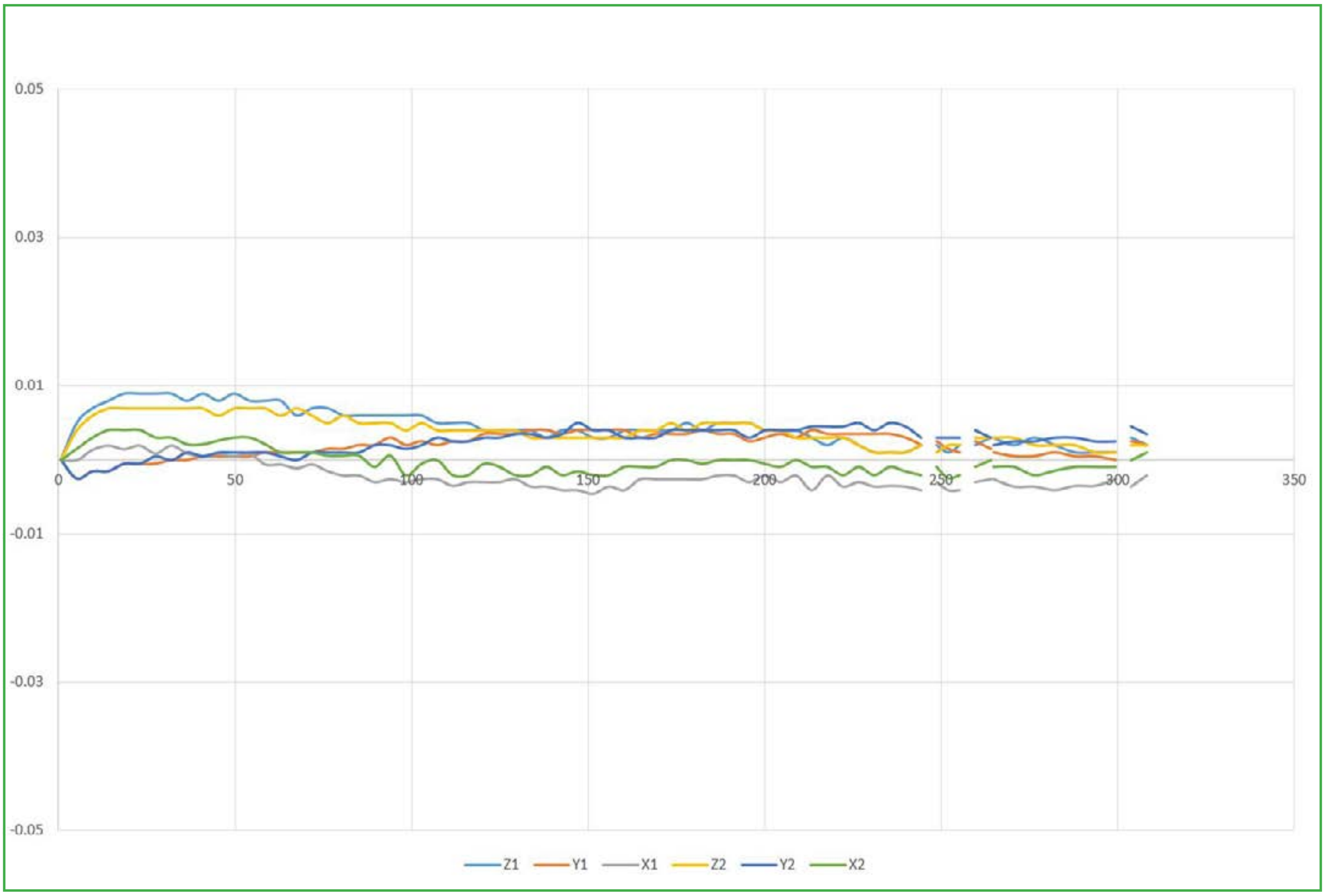
# iTEC SYSTEM RESULTS

## Conducted in Seoul, Korea



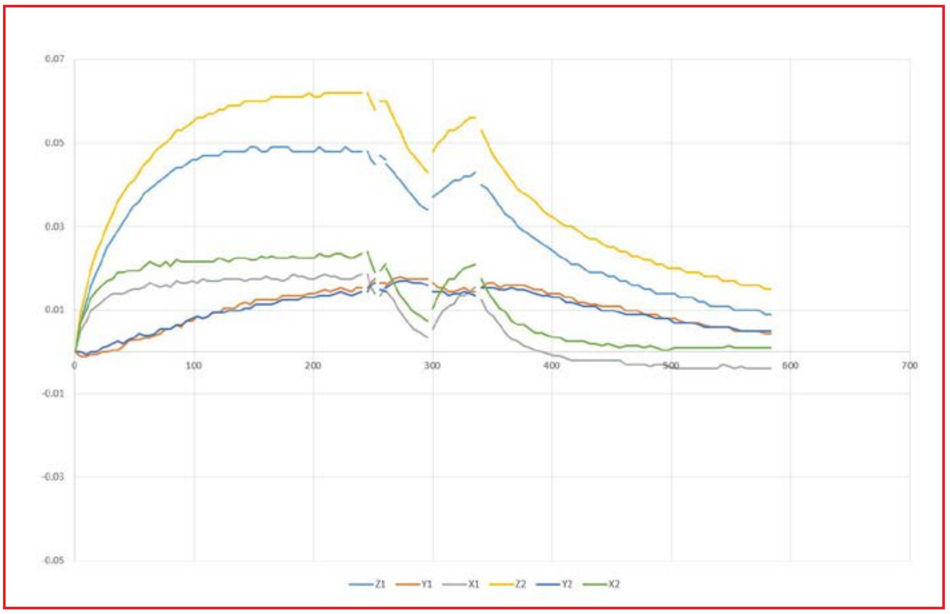

iTEC Off

iTEC On



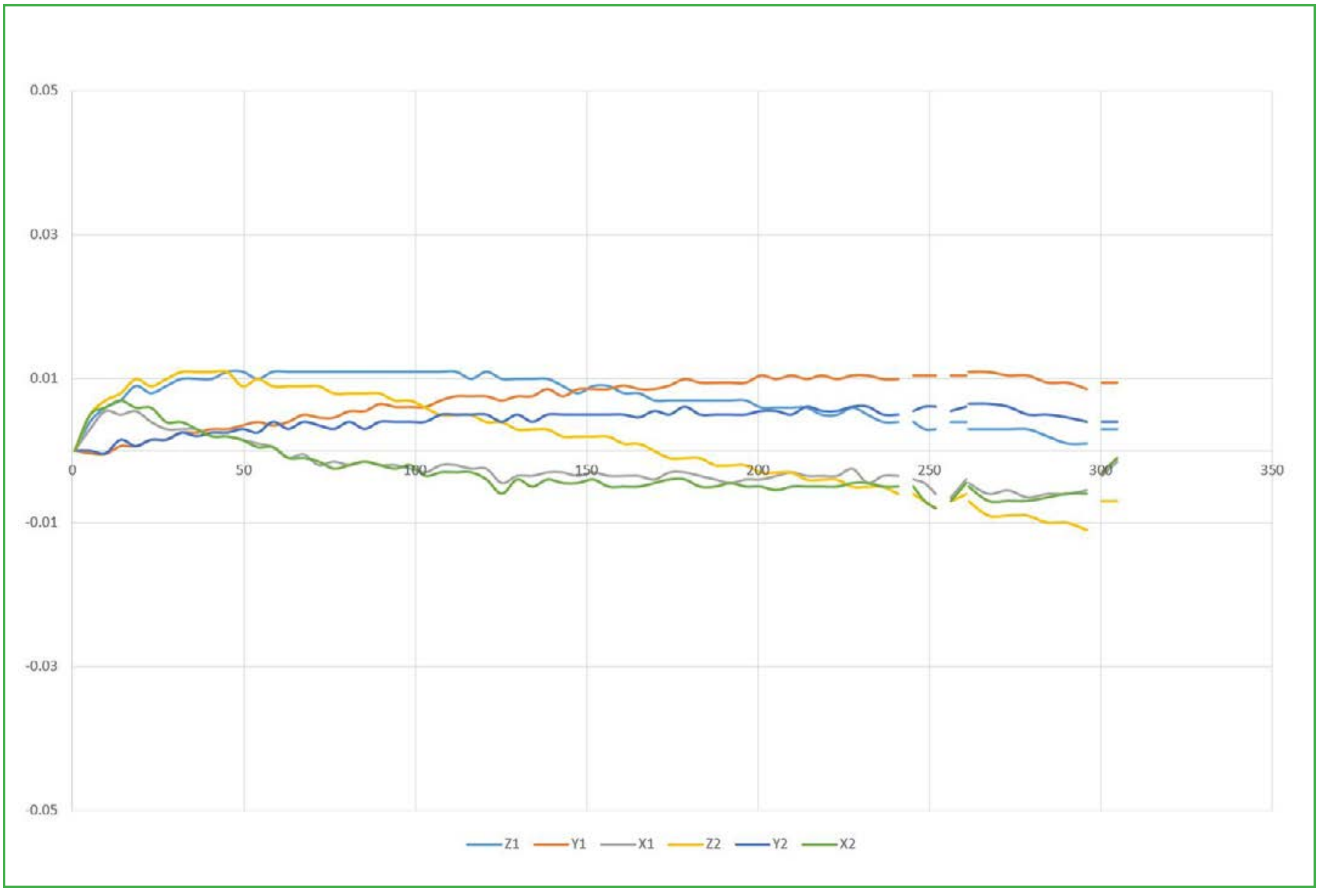
# iTEC SYSTEM RESULTS

## Conducted in California, USA

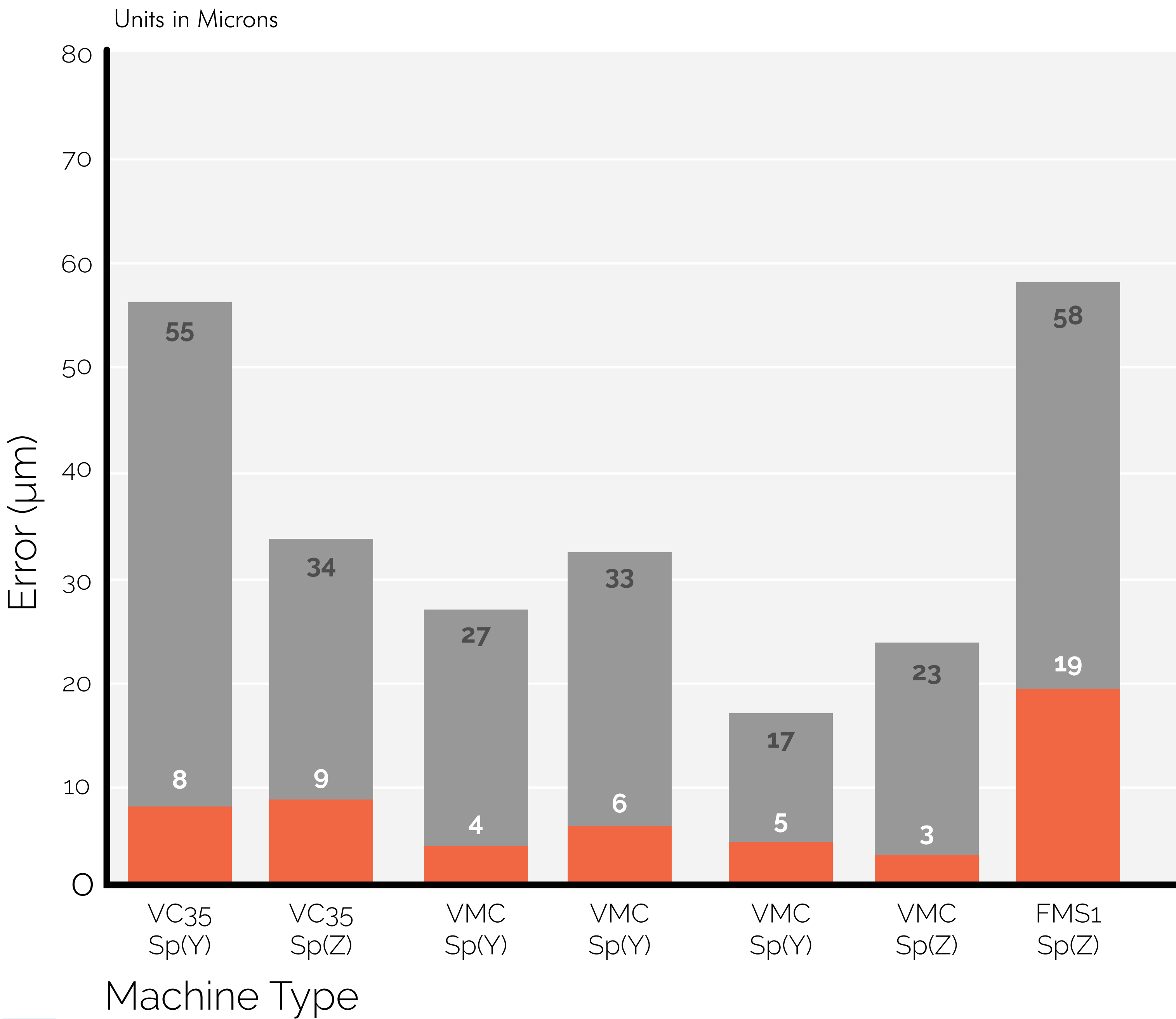



iTEC Off

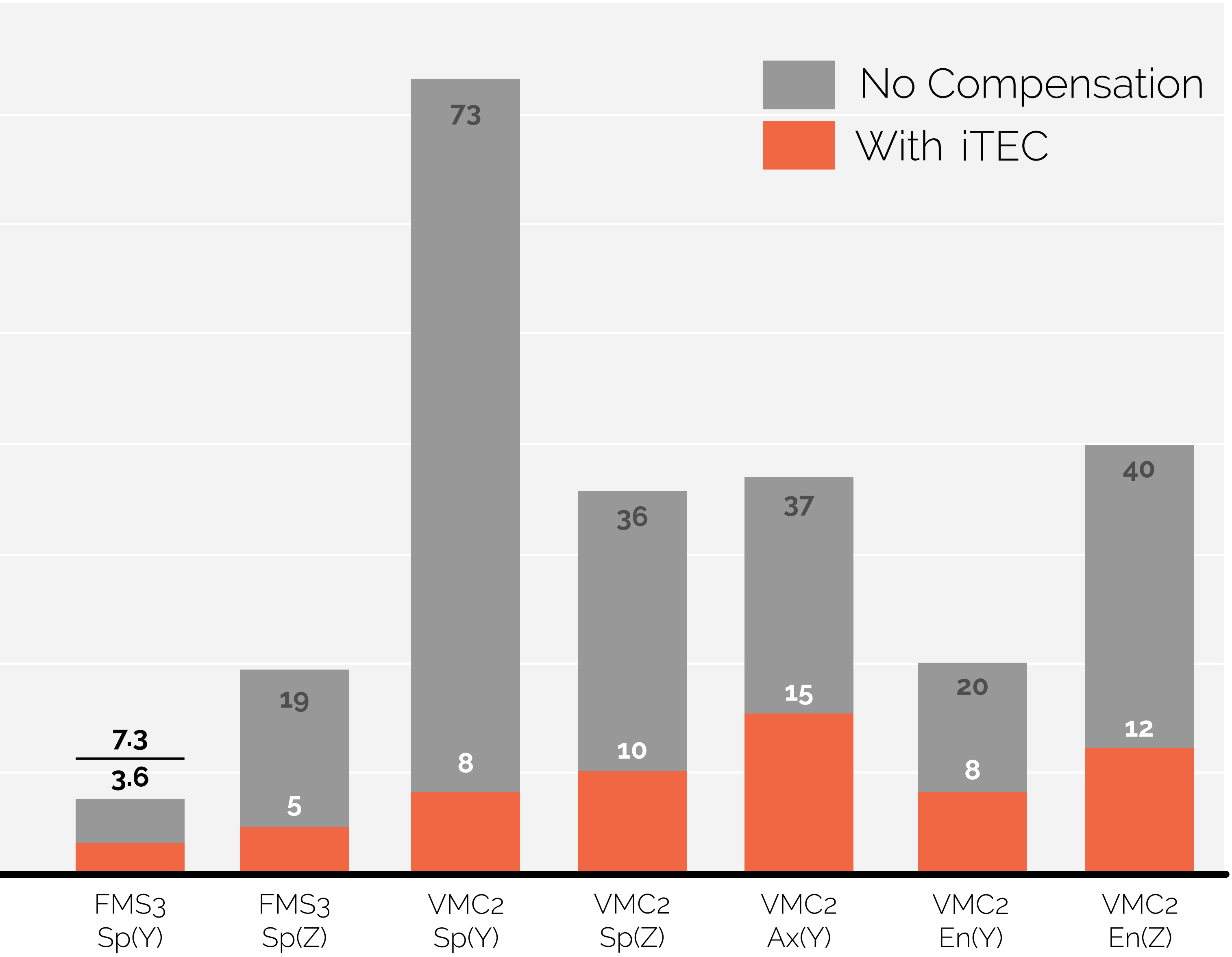
iTEC On



# TYPICAL THERMAL COMPENSATION IMPROVEMENTS WITH iTEC



## On average a **73% reduction was achieved** for ISO type measurements on a variety of machines.



# Thermal mapping is **machine model specific**. **No thermal recalibration is needed** once thermal compensation is installed!

After the heat build-up locations are identified, active temperature sensors are attached to structural elements where the heat build-up has been observed. The sensors will provide real time feedback of the changes in temperature.

## The thermal sensors

- The sensors can be applied individually or in strips of multiple sensors.
- The sensors have a low profile allowing them to be applied in confined areas.

Once the temperature sensors have been attached and connected a single heating and cooling cycle is performed while movements and temperatures data is collected.

## Thermal model calibration run

- A single heating and cooling cycle is performed.
- The typical length of the test is 180 minutes.
  - 90 minutes running the spindle to induce internally-generated heat
  - 90 minutes with no heating

The collected actual movement data is compared to the modelled movement and with this information the thermal model is calibrated.

Once the thermal model is completed a final test is performed with a random duty cycle.

As a result a seamless compensation is applied throughout the full range of machine travel even if one area of the machine has a change in temperature that varies from other areas.

# THE IMPLEMENTATION BASICS

## Implementing iTEC for individual machine tools

The individual machine model needs to be calibrated to compensate for thermal errors affecting the machine.
The thermal calibration process starts with the identification and evaluation of the generic and non-generic heat sources and their effects.
This is a process called Thermal Mapping and is unique to each individual machine model.

# WHY BUY iTEC?

The benefits of being able to produce a part that has a higher level of accuracy is very significant and will ultimately translate into an improvement of the financial bottom line of the business.

Higher accuracy means less waste by reducing the number of produced parts that do not meet the minimum required customer specifications.

Being able to repeatedly produce parts within the required specifications increases the machine's production efficiency resulting in more parts produced within the required specifications per hour of machine up-time.

Higher accuracy also improves the fit of the part in the final assembly. This reduces or entirely eliminates the need for rework and therefore decreases the assembly time.

Energy is saved as a result of the higher production efficiency. Less machine time for a batch of parts means that less energy is directly spent on the production.

Energy is also saved since the machine is better able to handle temperature variances. As a result the air conditioned environment control can be less stringent.

LOW COST solution to improve accuracy

MORE consistent accuracy

LESS production waste

INCREASED efficiency

DECREASED production cost

INCREASED production volume

INCREASED customer satisfaction

IMPROVED profit margins

# INDUSTRY EXAMPLES

## Mobile Computing and communication industry

Modern design engineers are specifying more accurate machining requirements which are unachievable without a thermal compensation system that works.

## Automotive industry

More accurate body panels on cars can provide smaller gaps which will reduce drag hence less fuel consumption. The DAPATECH systems also benefits the manufacturing of (automotive) gearboxes, increased accuracy improves the reliability.

## Aerospace industry

More accurate machine tools allows for extremely precise carbon fiber skins to be fitted without manual adjustments creating cheaper and more efficient aircraft.

# iTEC vs AI SYSTEMS

iTEC is based upon a physics model of the machine and machining process. It has been tested extensively on a large number of machines and has proven to be robust to small variations of the machine structure and over wide variation in operating environments.

Self learning (AI) models are very attractive because they can be quickly implemented on new machine types. It is likely that you can get very promising results from one test. We have been researching into these technologies for almost 10 years. The main drawbacks of this approach for use in industrial applications at this time are:

- The AI can learn a false solution. Although it numerically optimises the problem, the variables are not physics based, they are a mathematical way of lumping together different parts of the machine. Such a "blackbox" approach can therefore not be interrogated for robustness without extensive trials and confidence in the accuracy may reduce if operating environments vary beyond the limits used in the optimisation.
- Because the AI learns a solution for the particular machine, it is not clear that the model can then be transferred to other machines of the same type without further training being required. This is particularly arduous if you need to compensate for environmental and internally generated effects because of the length of time required to train each model. For each AI model, there should also be a validation routine. This again will increase the testing time for each machine, particularly when the validation should include alternate operating conditions.
- Training can be affected by noise in the system. This could come from sensors or just poor test regimes, therefore the AI model could learn a bad solution while attempting to compensate some of the noise during the optimisation. This may make the output more sensitive to noise in future operating conditions and potentially affect surface quality where relatively rapid changes occur as the model reacts to the noise.
- From our experience, it can be relatively easy to get an AI model to show very promising results. This is something to bear in mind if doing comparative trials between a physics-based model and an AI model. While it may work for one situation, it does not extrapolate in the same way that physics based models would extrapolate.

We do view such AI models as interesting research for the future. Indeed, we are looking into them quite extensively. However, at this time we do not believe they are ready for full commercialisation due to the inherent risk to the accuracy of the manufactured component.

Professor Andrew Peter Longstaff
**Huddersfield University**

# THERE IS NOTHING ARTIFICIAL ABOUT iTEC INTELLIGENCE

Unlike other systems coming to market, **iTEC is not predictive and DOES NOT rely on assumptions or artificial intelligence.** Once iTEC maps the machine it applies **thermal compensation in real-time** regardless of machine wear or operating conditions.

It is a position dependent system which **enables it to compensate for machine bending and distortion.**

## No other system achieves the accuracy and consistency of iTEC

## PREDICTIVE SYSTEMS

Work on Preset values & Run time.

Act on assumptions that everything will act in the same way each time. The reality is different.

Each machine has to be set up individually.

iTEC

Intelligent Thermal Error Compensation

Works on algorithms and **real-time** feedback from thermal sensors.

Works consistently under any conditions

Accommodates non-rigid body thermal errors and machine bending.

## FOR A STANDARD MACHINE TOOL TO ACHIEVE ITS OPTIMUM PERFORMANCE YOU WOULD HAVE TO...

House the machine in a thermally stable environment

Employ multiple cooling methods

Minimise machine hydraulics

Use coolant chillers

Constantly adjust and probe whenever there are changes to the environment or machine parts

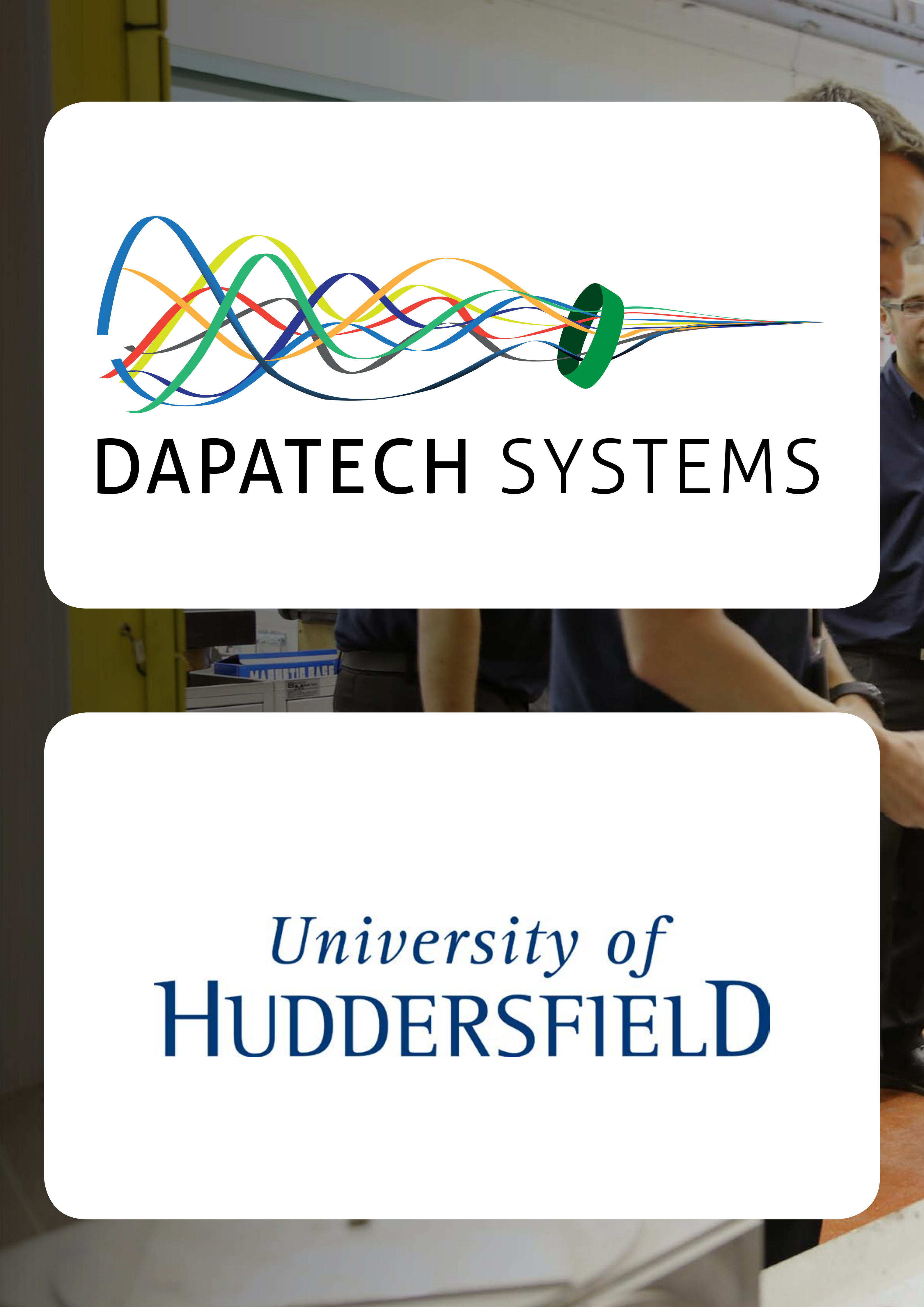
# Exceed These Results By Installing iTEC

## The World's First Real-Time Thermal Compensation System

R


**Plug & Play**

Install and walk away



DAPATECH SYSTEMS

University of
HUDDERSFIELD

# The iTEC system has been developed by DAPATECH in partnership with the University of Huddersfield

DAPATECH SYSTEMS

Intelligent Thermal
Error Compensation

– PLUG & PLAY SYSTEM –

www.dapatech.com