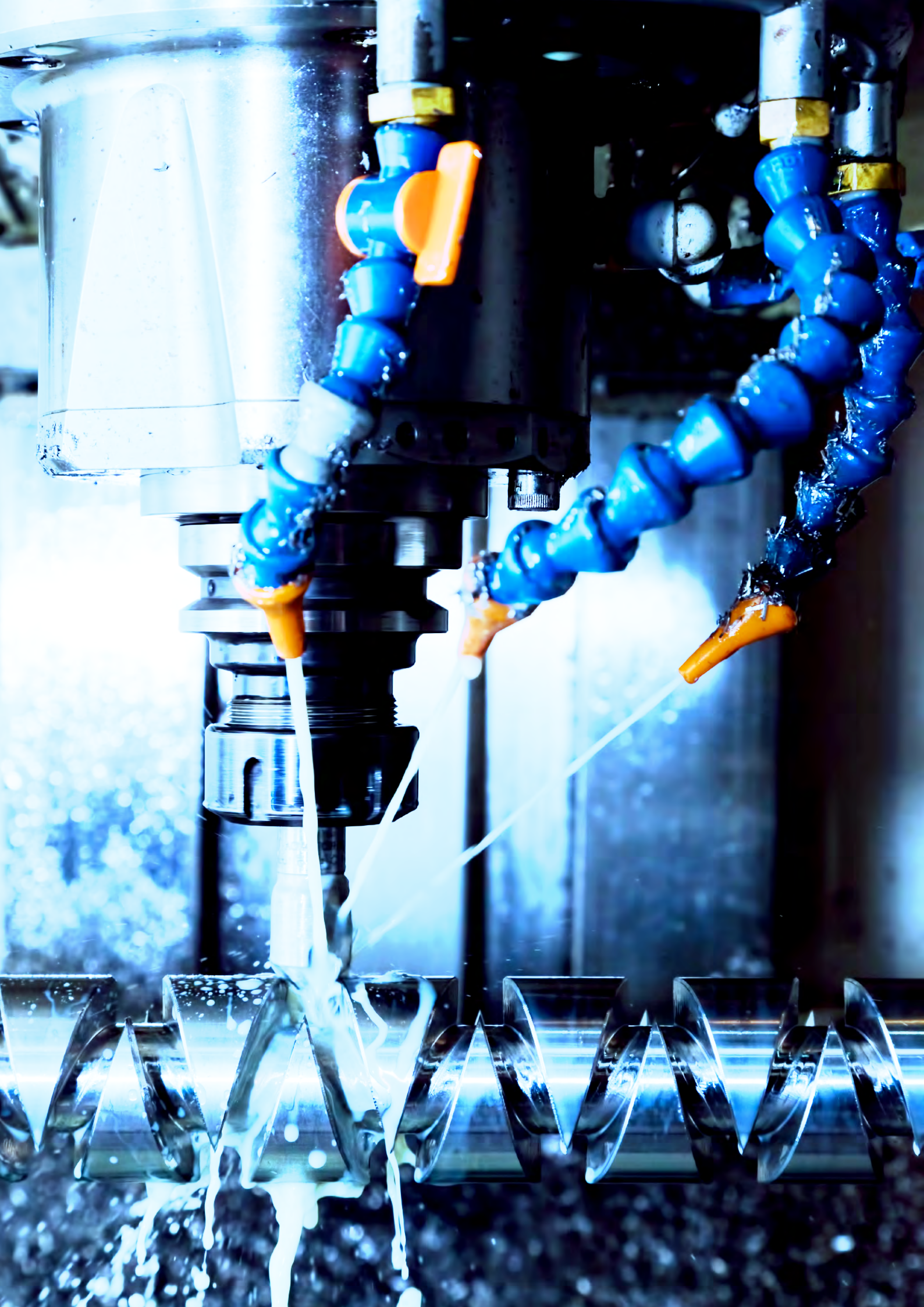
DAPATECH SYSTEMS

GEOMETRIC & THERMAL ERROR COMPENSATION



DAPATECH SYSTEMS

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WHY GTEC OR iTEC

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SUCCESS OF OUR SYSTEMS

ERROR REDUCTION

Error compensation is an effective and cost efficient way to correct errors that cannot easily be eliminated by error avoidance.

The accuracy of a machine tool is influenced by various errors sources, error reduction aims to cancel or reduce to effect of these errors on the machining accuracy and final dimensions of the produced part.

There are two approaches to improve machine tool accuracy:

1. Error avoidance
2. Error compensation

Error avoidance is initially done during the design and manufacturing stage where the focus is put on stiffness, damping, material etc.

Error compensation, on the contrary, is not aimed at avoiding errors. Errors are allowed to manifest themselves so they can be measured and compensated.

Ultimately there are physical limits to what can be accomplished through design and manufacturing of a machine tool to increase accuracy. Additionally, to strive for an ever increasing degree of accuracy, by altering the physical properties of a machine, has an exponentially increasing financial cost.

Error compensation software is an effective and cost efficient way to handle errors that cannot easily be eliminated by error avoidance. It is relatively inexpensive and far easier to implement when for instance compared to a mechanical realignment. Moreover it offers high adaptability and flexibility with a minimum of effort since the software can easily be updated to accommodate changes in the errors.

THE NEED FOR ERROR COMPENSATION

There are 21 components in the geometric error of a three-axis machine tool and a five-axis machine tool has 31 components in the geometric error. These errors affect machine tool accuracy and therefore the accuracy of the produced part.

The main errors are:

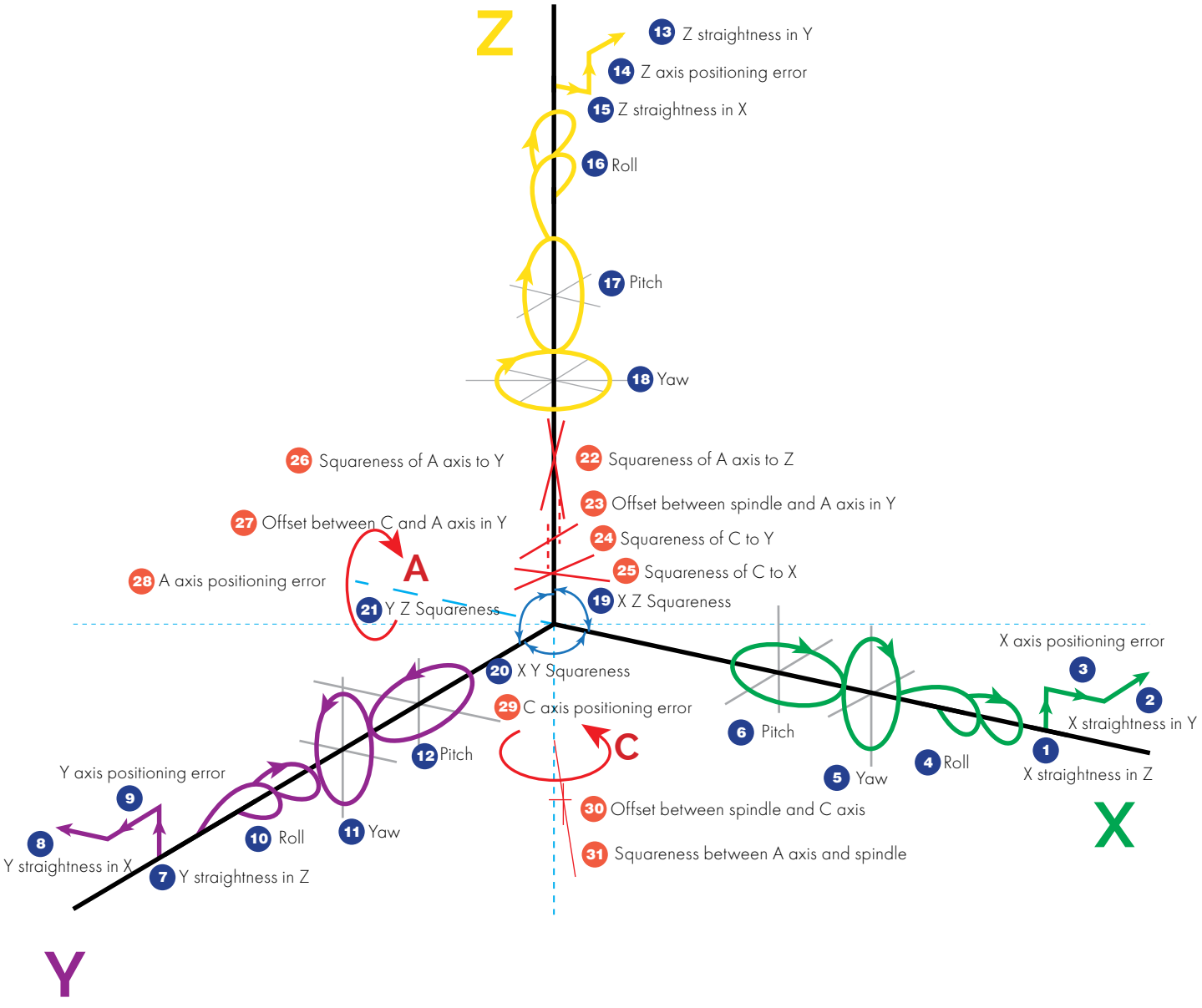
- Squareness between each pair of axis (the larger the machine is the greater the error)
- Linear inaccuracy on the major axis and
- Roll, pitch and yaw for each axis

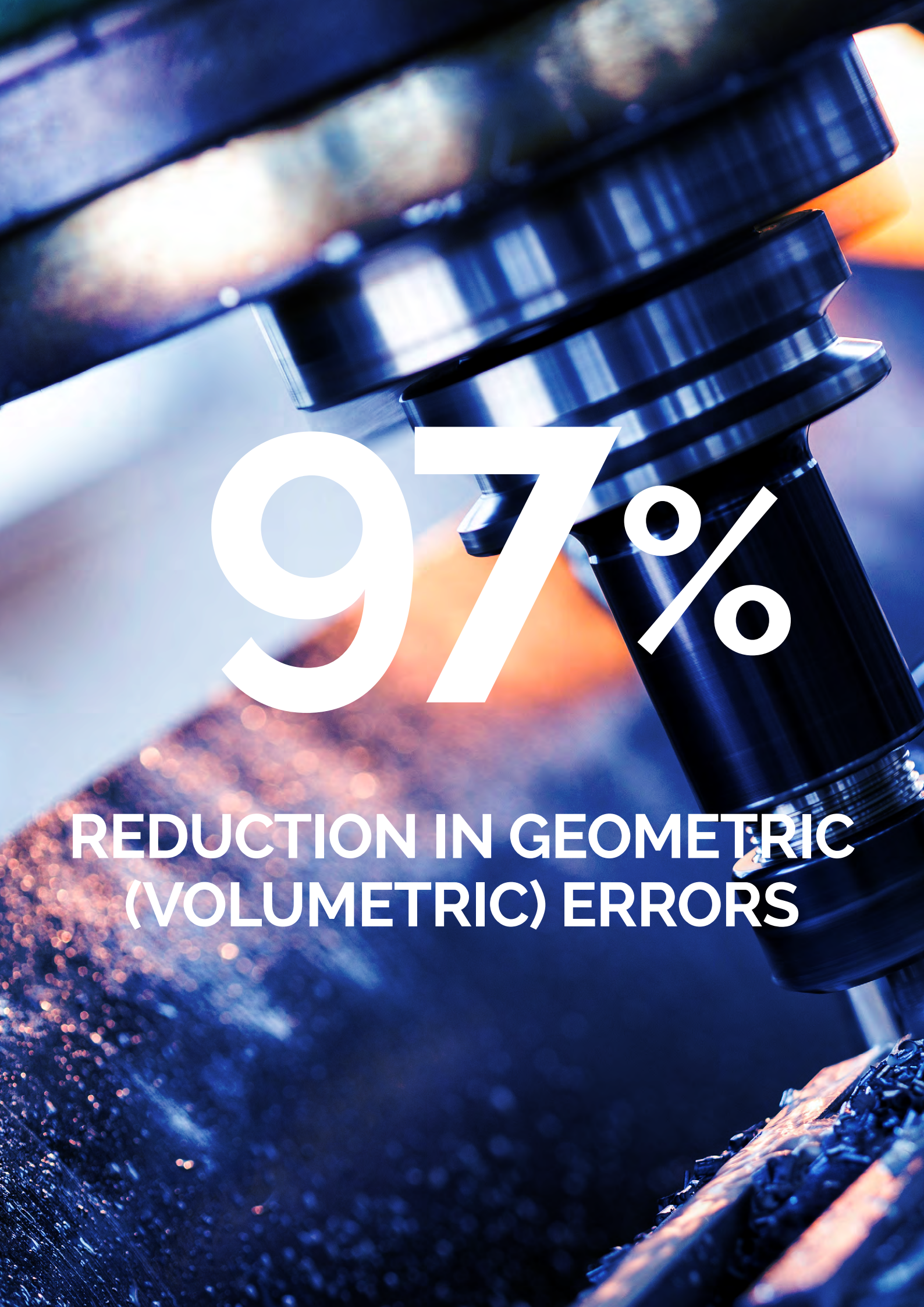
However, the biggest challenge in achieving consistent accuracy of a produced part is managing the effect of temperature changes on the machine and the part itself.

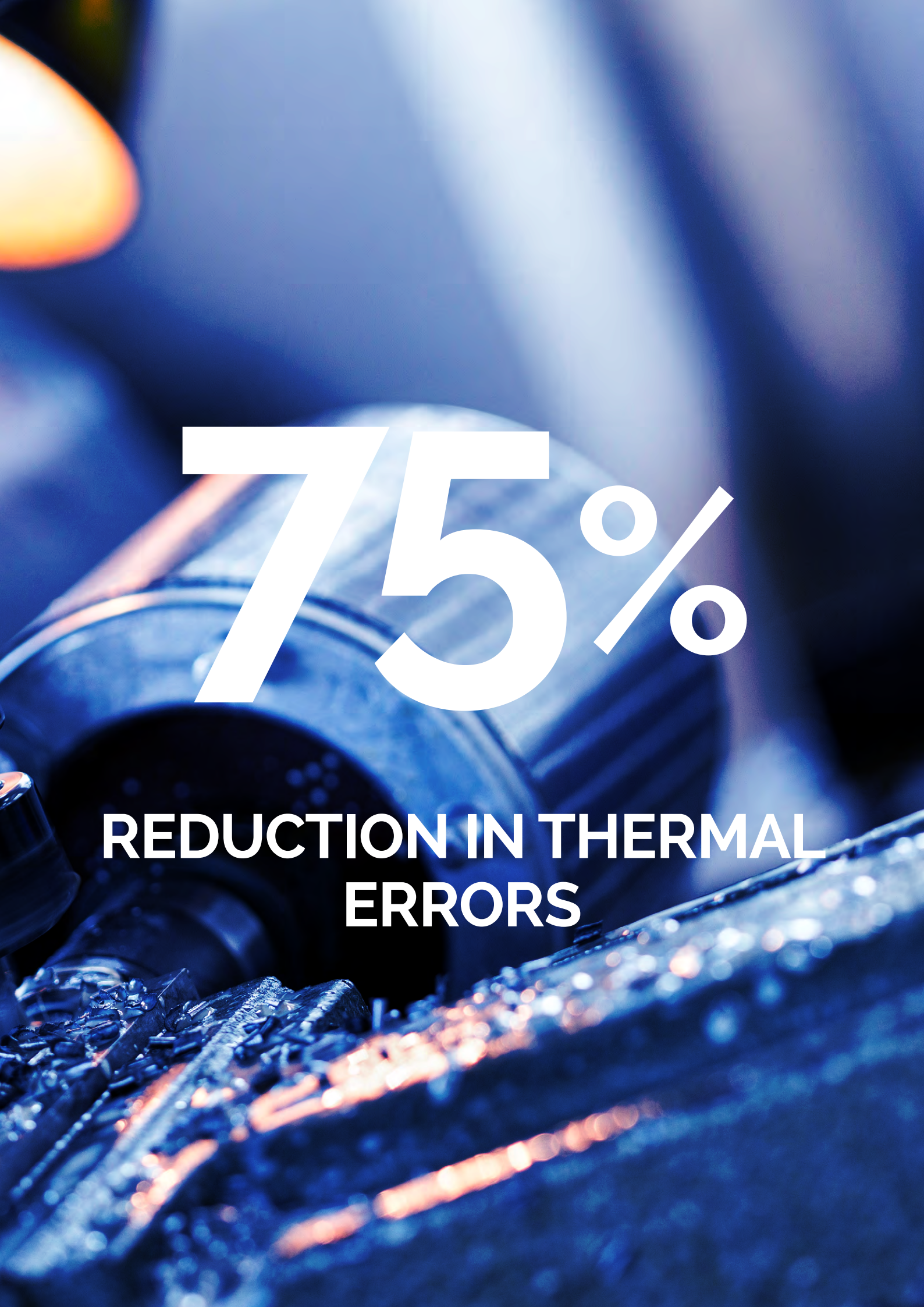
Temperature variations not only affect the distance traveled along an axis but also changes the shape and structure of the machine tool. This effect alters the static geometric (volumetric) calibration and as a result making it incorrect and as a result ineffective.

The biggest challenge in achieving consistent accuracy of a produced part is managing the effect of temperature changes on the machine and the part itself.

Diagram of the 21 Geometric Errors for a three-axis machine & 31 Errors for a five-axis machine with AC rotary fork head or tilt rotary table




97%
REDUCTION IN GEOMETRIC
(VOLUMETRIC) ERRORS


75%
REDUCTION IN THERMAL ERRORS

DAPATECH ERROR COMPENSATION SYSTEMS

DAPATECH currently produces two error compensation systems. These two systems have been developed in partnership with the University of Huddersfield in the UK.

The GTEC system or Geometric AND Thermal Error Compensation system. As the name suggest it compensates for geometric (volumetric) AND thermal errors.

The iTEC system or Intelligent Thermal Error Compensation system. This system focusses solely on the compensation of thermal errors

Extensive and rigorous tests have shown that geometric (volumetric) errors can be reduced up to 97% and thermal errors can be reduced up to 75%.

Both the GTEC and iTEC system are available for three and five-axis machine tools.

The GTEC & iTEC Systems have been developed by DAPATECH in partnership with the

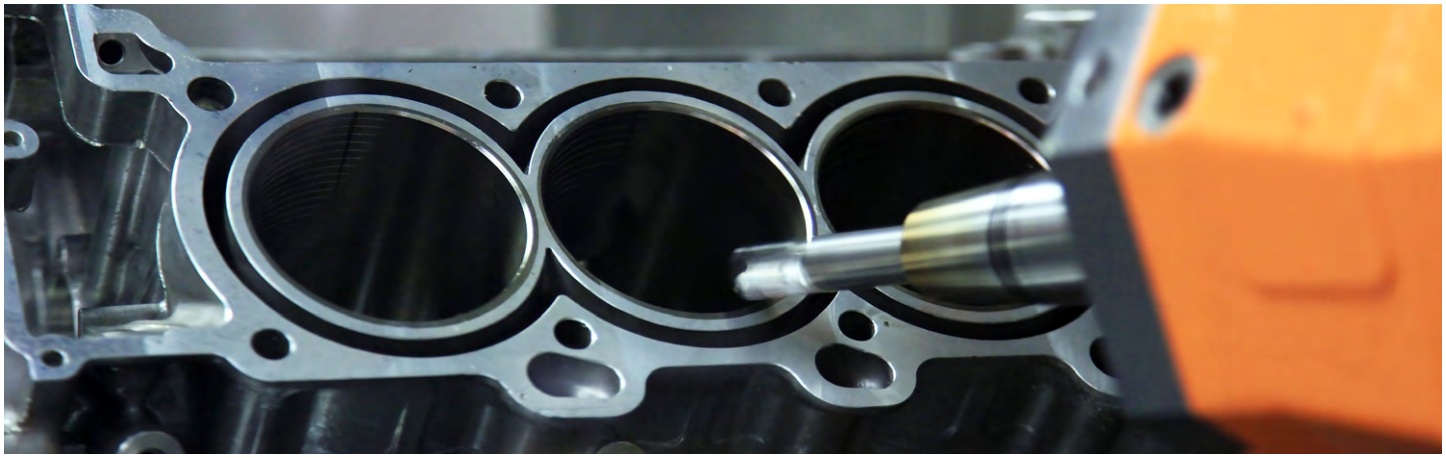
University of HUDDERSFIELD

GTEC

GEOMETRIC & THERMAL ERROR COMPENSATION

GTEC is DAPATECH's solution for the linear effect of geometric (volumetric) and thermal errors. GTEC electronically enhances the accuracy of CNC machine tools.

The DAPATECH systems have achieved Geometric (volumetric) Error reductions of **97%** & Thermal Error reductions of **75%**

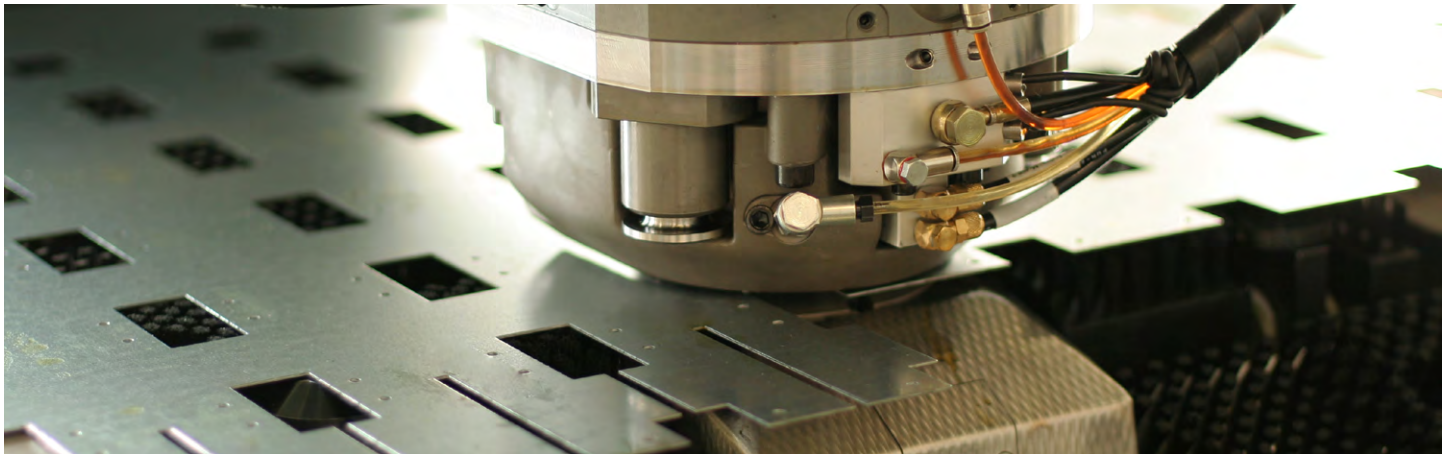


THE GTEC SYSTEM FACTS:

- Geometric (volumetric) AND thermal error compensation combined in ONE system
- Completely controller independent (installed between controller and machine)
- Reduces geometric (volumetric) error by up to 97%
- Reduces thermal errors by up to 75%
- ONE algorithm compensates for all 21 errors (three-axis machine) or
- ONE algorithm compensates for all 31 errors (five-axis machine)
- Fully customizable to fit any machine tool environment
- Fully adaptable thermal compensation for reduction of all systematic thermal effects
- Thermal compensation is applied infinitely AND in real time
- Physical switch for direct deactivation and activation of the GTEC system to verify its functionality

iTEC

INTELLIGENT THERMAL ERROR COMPENSATION

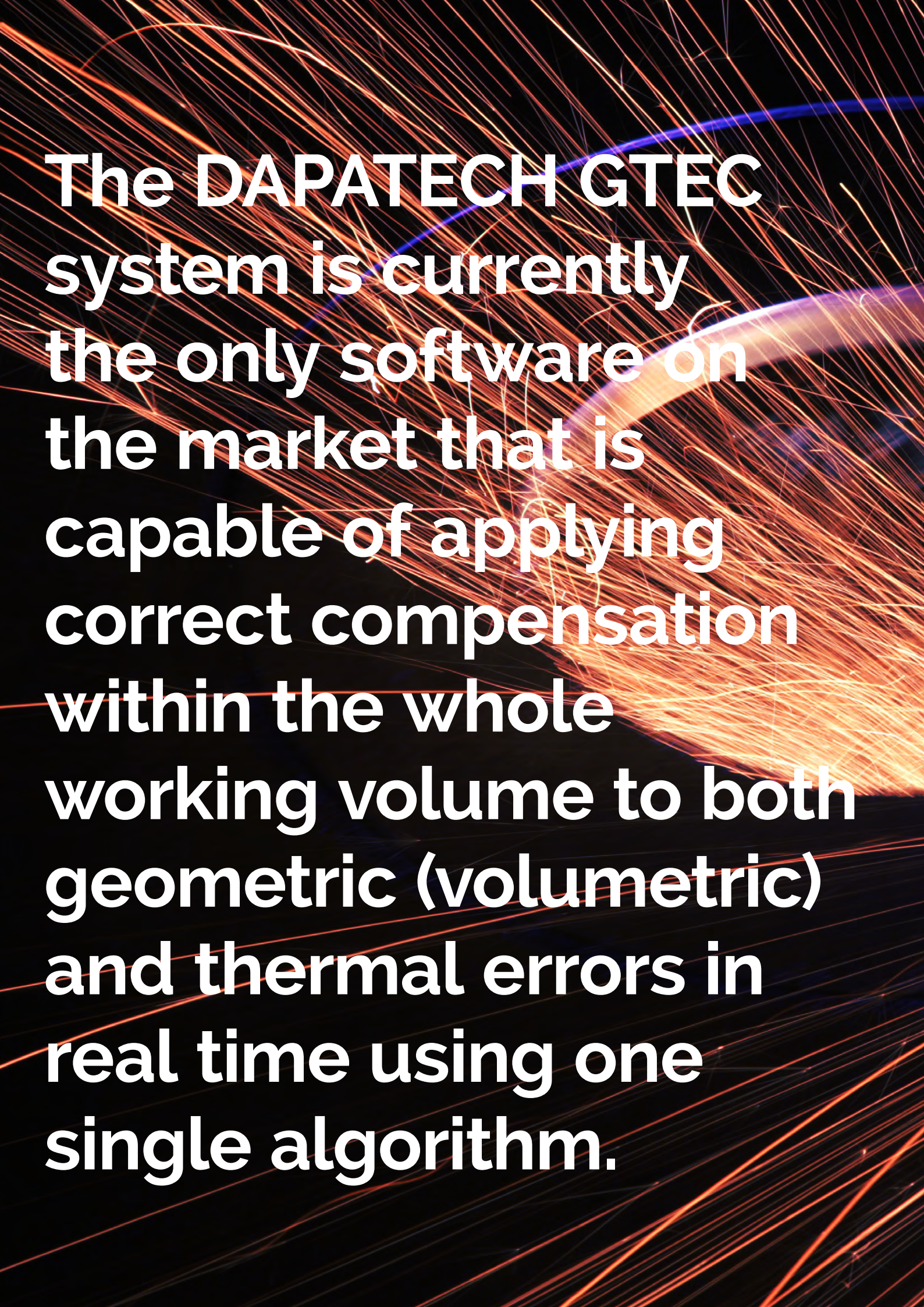


iTEC is DAPATECH's solution for the linear effect of thermal errors and electronically enhances the accuracy of CNC machines tools.

The **iTEC** system is a means of **correcting** the **linear effect** of thermal errors.

THE iTEC SYSTEM FACTS:

- Software based system
- Either fully integrated into the controller or
- Added as an 'Plug & Play' external box
- Reduces thermal errors by up to 75%
- Works seamlessly alongside existing geometric (volumetric) compensation systems
- Thoroughly tested on Fanuc, Siemens and Osai controllers


The DAPATECH GTEC system is currently the only software on the market that is capable of applying correct compensation within the whole working volume to both geometric (volumetric) and thermal errors in real time using one single algorithm.

THE GTEC SYSTEM

The GTEC system compensates all geometric (volumetric) AND thermal errors that affect positioning accuracy throughout the entire volume of the machine.
One single algorithm applies compensation to the full array of the three or five axes covering all 21 errors (three-axis machine) or 31 errors (five-axis machine) including the effects of expansion and contraction caused by temperature changes.

The algorithm also compensates for varying reversal positions by using bi-directional data.

To achieve a high level of accuracy and smoother seamless contour machining the algorithm interpolates between target positions to apply a new compensation every time a micron of error is detected.

The DAPATECH GTEC system is currently the only software on the market that is capable of applying correct compensation within the whole working volume to both geometric (volumetric) and thermal errors in real time using one single algorithm.

G|T|E|C

Geometric & Thermal Error Compensation

The DAPATECH GTEC system is currently the **only software on the market** that is capable of applying **correct** compensation within the **whole working volume** to both **geometric (volumetric) and thermal** errors **in real time** using **one single algorithm.**

THE iTEC SYSTEM

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

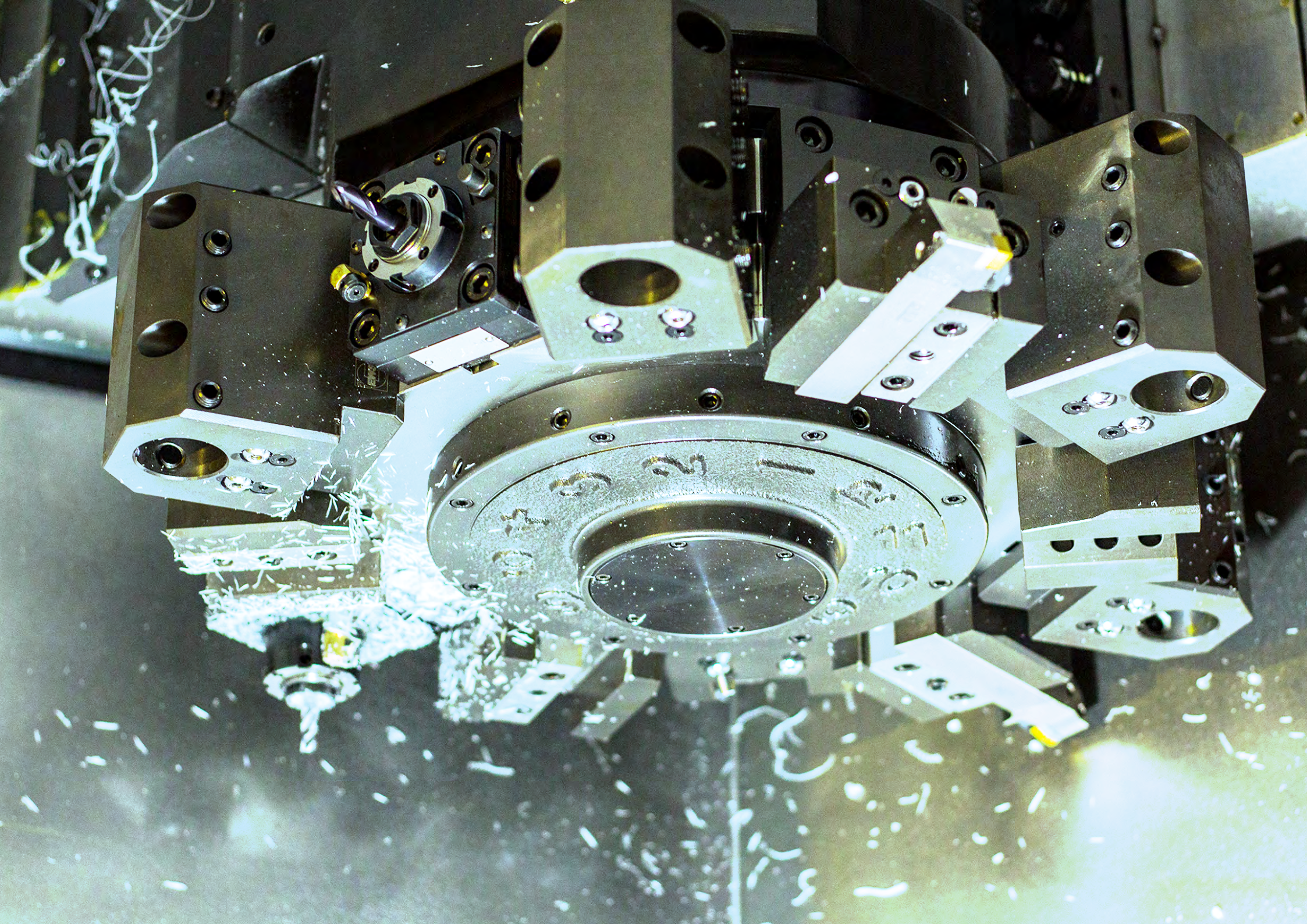
Even 1 degree of thermal expansion of key components of the machine can cause positioning inaccuracies and consequently machining inaccuracies of tenths of millimeters in a 6 meter travel machine.

The iTEC system can be either fully integrated into the machine tool controller or the system can interface with the machine via an external 'Plug & Play' addition.

iTEC

Intelligent Thermal Error Compensation

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



THE IMPLEMENTATION BASICS

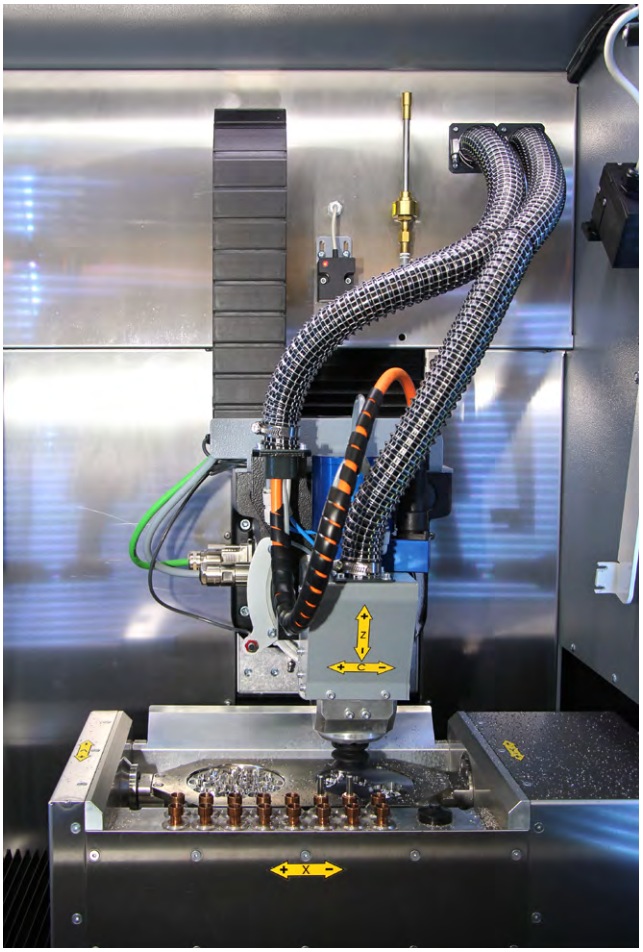
GTEC

Firstly the machine is geometrically calibrated to the maximum achievable accuracy throughout the entire working volume to allow full utilization of the machine's capabilities. This will ensure that the machine can, at all times, easily and consistently produce a part that requires less accuracy than the machine's maximum calibrated accuracy.

During the calibration period various measurements are taken to identify and quantify the existing deviations. After the calibration process the system is left in automatic mode, no further operator intervention is required.

The system only requires one annual (re)calibration to ensure optimized performance.

Should a disruptive event take place that could have affected the existing geometric errors, such as a collision, a non-periodical calibration should be performed.



GTEC and iTEC

As a second stage in the calibration process for the GTEC system and as the only stage for the iTEC system, the machine 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.

Thermal mapping is **machine model specific** and is unique to each machine model. Under normal circumstances **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

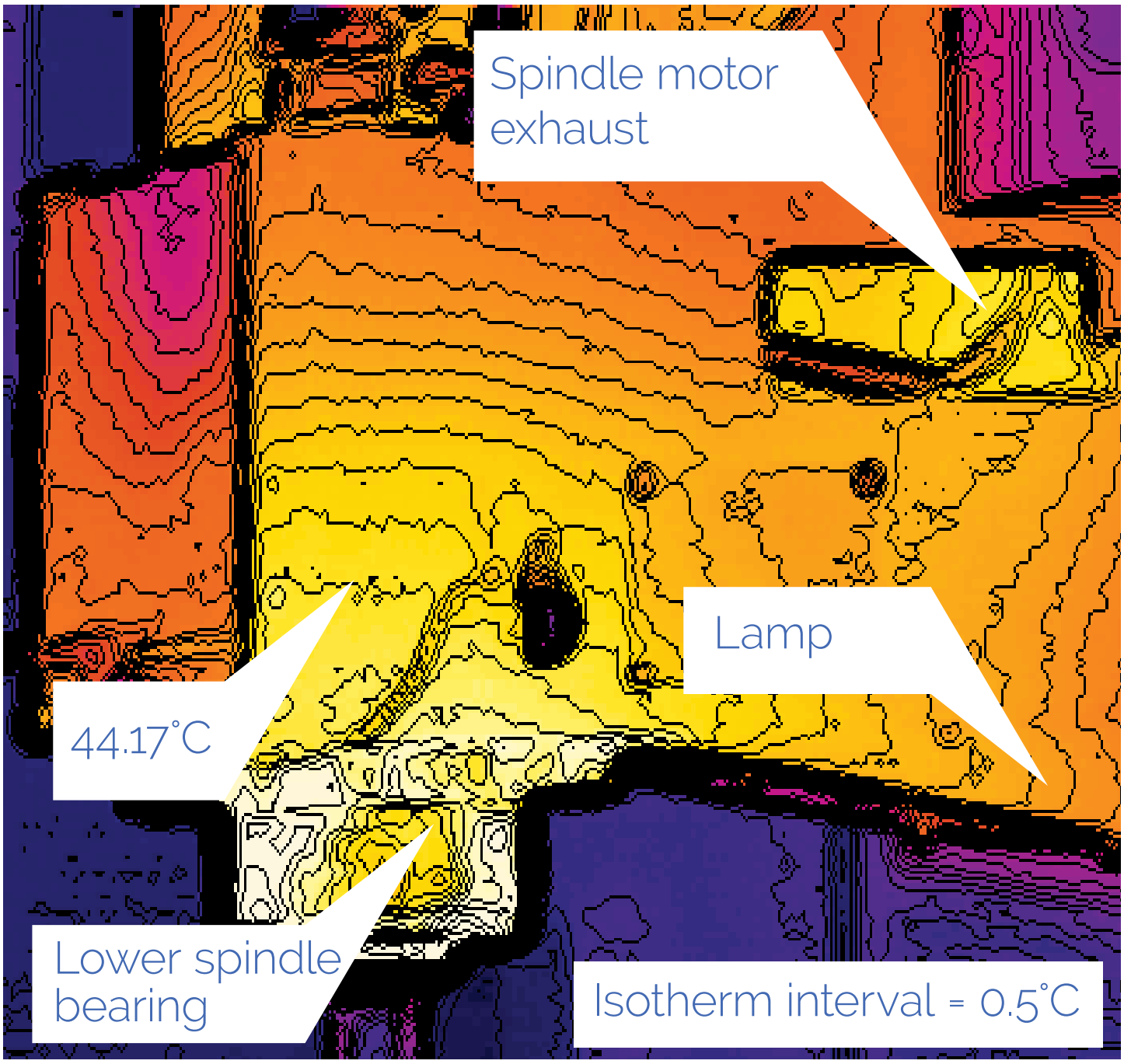
- A single heating and cooling cycle is performed.
- The typical length of the test is 180 minutes.
  - 90 minutes running the spindle to induce internally-generated heat
  - 90 minutes with no heating
- Further testing might be required if ambient changes show to have a significant effect.

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.

THERMAL IMAGING USED TO IDENTIFY HEAT BUILD-UP



CORRECT 4TH & 5TH AXIS ERROR COMPENSATION

All CNC machine tools are to a certain degree geometrically imperfect and have mechanical errors. The GTEC system will not physically change those mechanical errors but will only electronically via software target the tool point position to compensate for those errors.

To achieve consistent and accurate compensation it is essential to apply geometric (volumetric) 4th axis & 5th axis error compensation correctly. It must be applied through one single algorithm so that the tool point position is corrected seamlessly and in an infinitely compensated way throughout the machine volume.

If the 4th axis and 5th axis error compensation is applied independently of the standard three-axis compensation then the tool point error will likely be worsened in some positions within the machine.

The GTEC system is capable of applying and re-applying the 4th axis and 5th axis error compensation infinitely throughout the machine movements in conjunction with the standard three-axis error compensation to ensure correct tool point positioning.

The GTEC system is capable of **applying and re-applying** the 4th axis and 5th axis error compensation **infinitely** throughout the machine movements in **conjunction with the standard three-axis error compensation** to ensure correct **tool point positioning.**

WHY BUY GTEC OR 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 into 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

Green energy industry

More accurate gearboxes and gears for wind turbine generators enable more power to be produced with less noise pollution and longer economic life without expensive breakdowns.

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.

There are numerous other examples: satellites industry, communications industry, military industry, etc. where improved accuracy can make a significant difference.

Whether the business is involved in high volume mass production or low volume highly customized production, if there is a certain level of accuracy required, the DAPATECH systems are very likely to have a positive impact on the production.

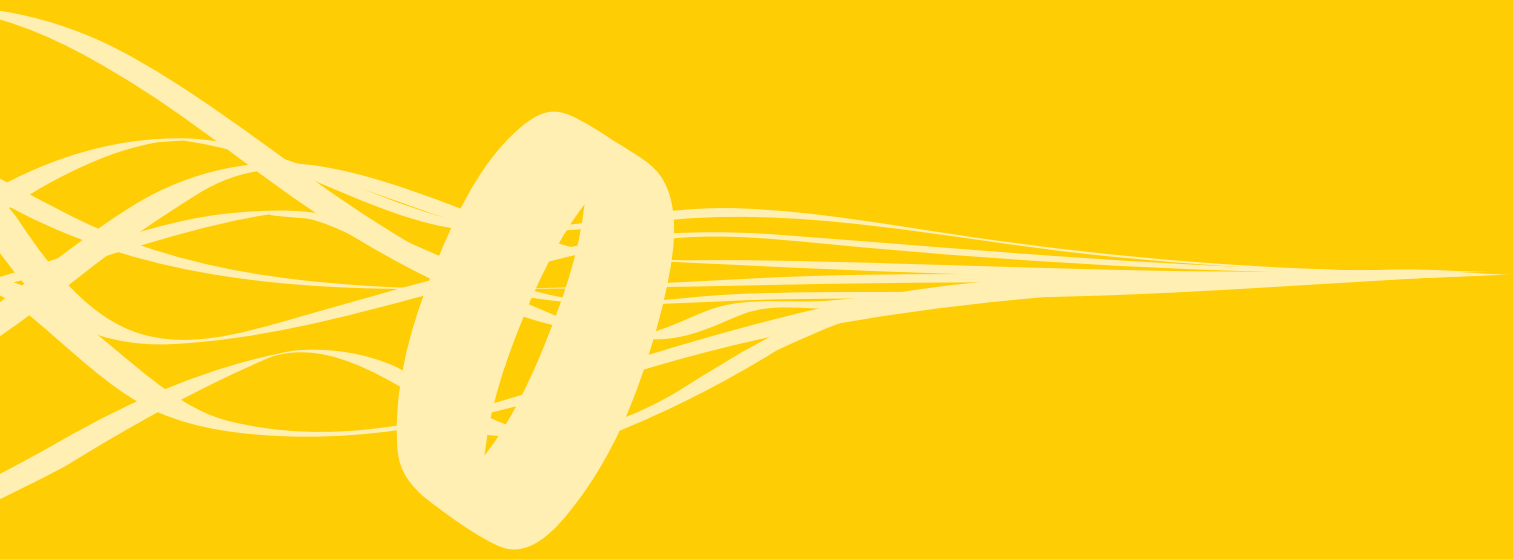
97%

AVERAGE GEOMETRIC
(VOLUMETRIC) ERROR REDUCTION

75%

AVERAGE THERMAL
ERROR REDUCTION

DAPATECH

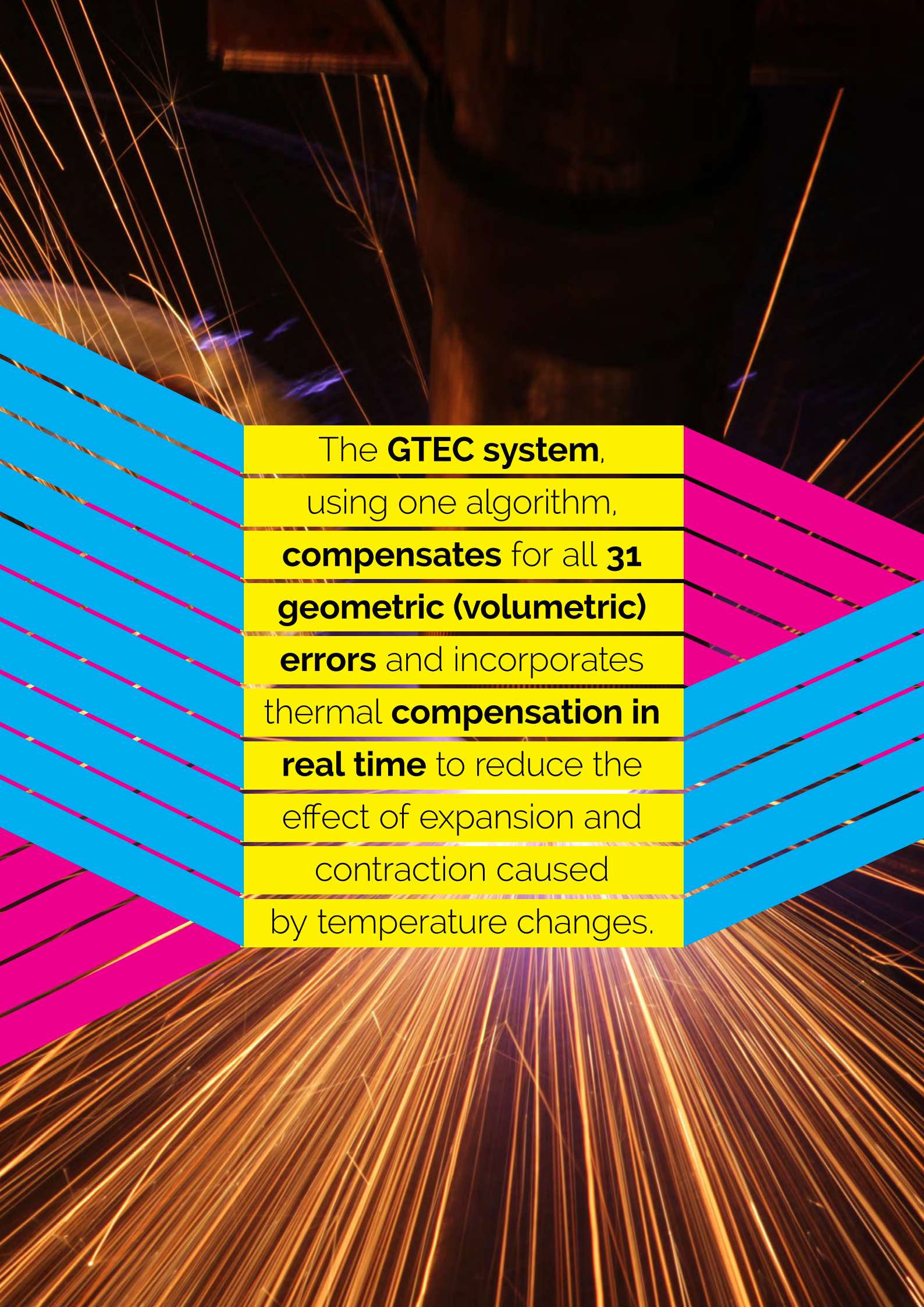


31	1
No. OF ERRORS WHICH GTEC COMPENSATES FOR	No. OF ALGORITHMS USED TO CORRECT ALL 31 ERRORS

SYSTEMS

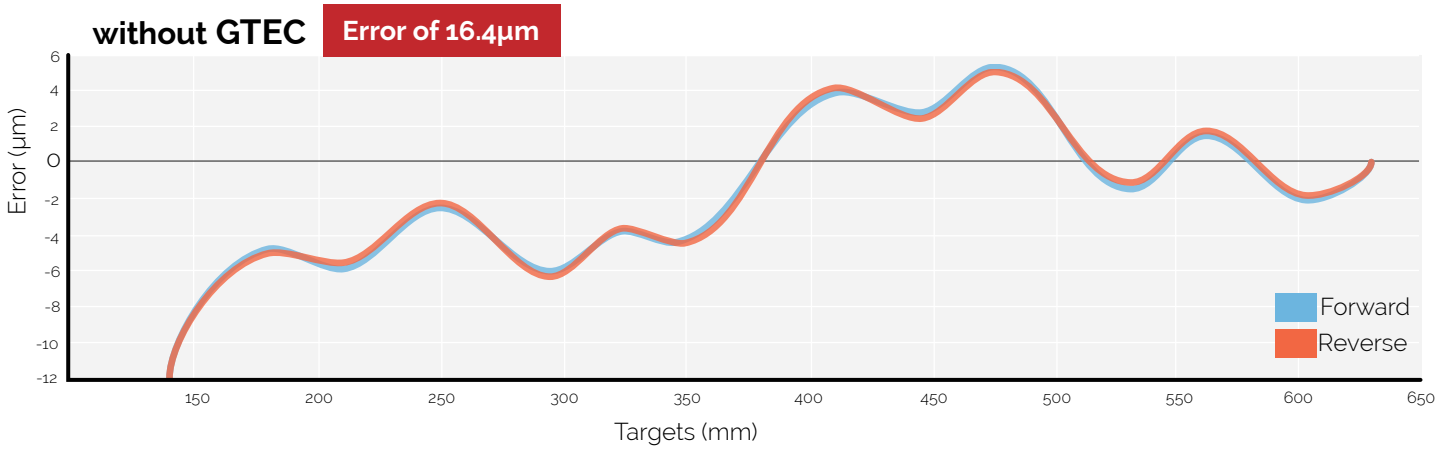
COMPARISON OF COMPENSATION SYSTEMS

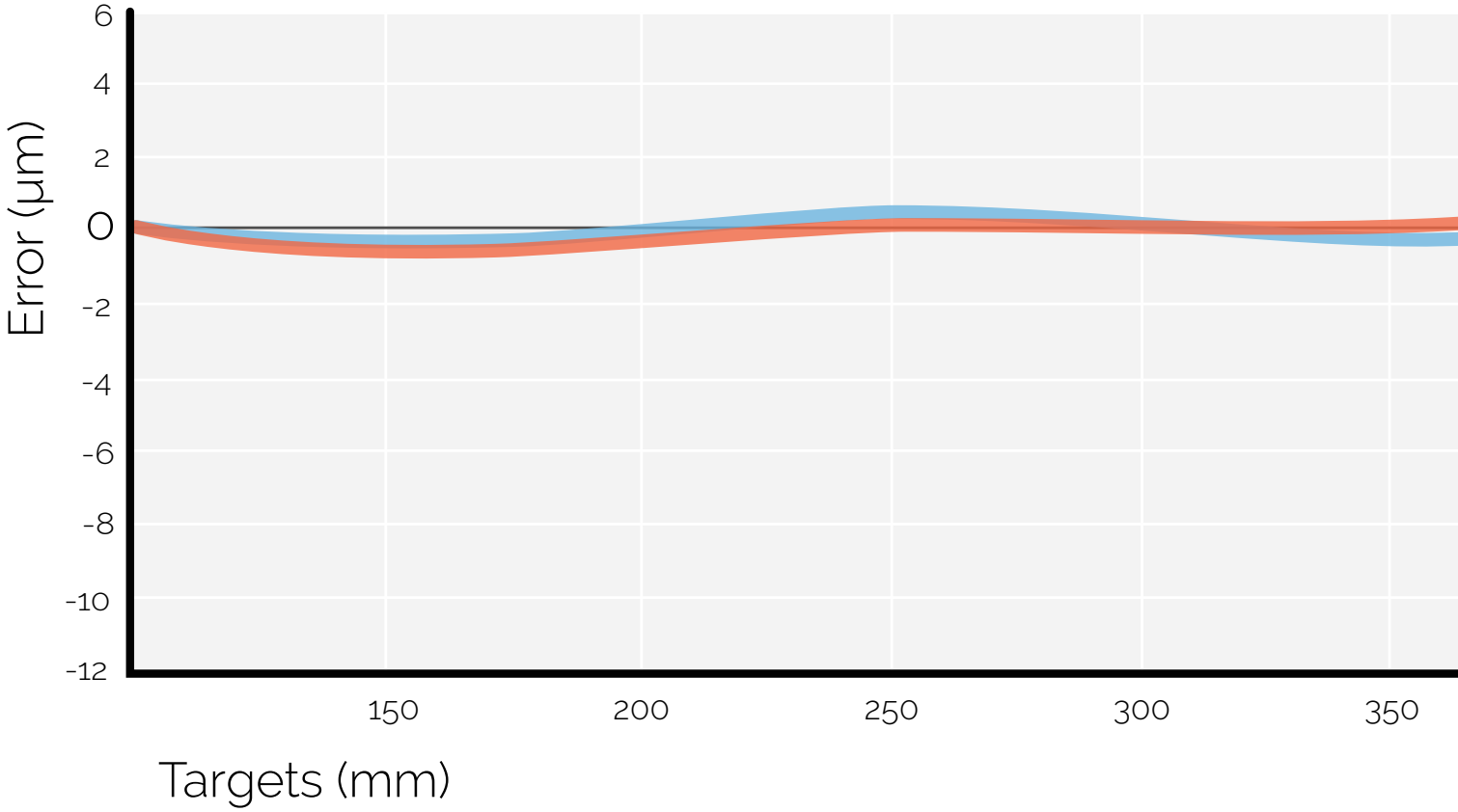
Standard CNC Compensation	GTEC Geometric & Thermal Error Compensation	iTEC Intelligent Thermal Error Compensation
Only compensates for a small number of error sources.	Compensates for all geometric and thermal error sources that affect positioning accuracy throughout the whole volume of the machine.	Compensates for all thermal error sources that affect the machine.
Often only has a single reversal value (backlash).	Utilises bi-directional data to correct for varying reversal.	Utilises bi-directional data to correct for varying reversal.
Is often restricted by table-size, so limits the resolution of the compensation.	Interpolates between target positions to apply a new compensation every time a micron of error is predicted – giving better accuracy.	Interpolates between target positions to apply a new compensation every time a micron of error is predicted – giving better accuracy.
Thermal compensation is limited.	Flexible thermal compensation system allows reduction of all systematic thermal effects.	Flexible thermal compensation system allows reduction of all systematic thermal effects.



The **GTEC system**, using one algorithm, **compensates** for all **31 geometric (volumetric) errors** and incorporates thermal **compensation in real time** to reduce the effect of expansion and contraction caused by temperature changes.

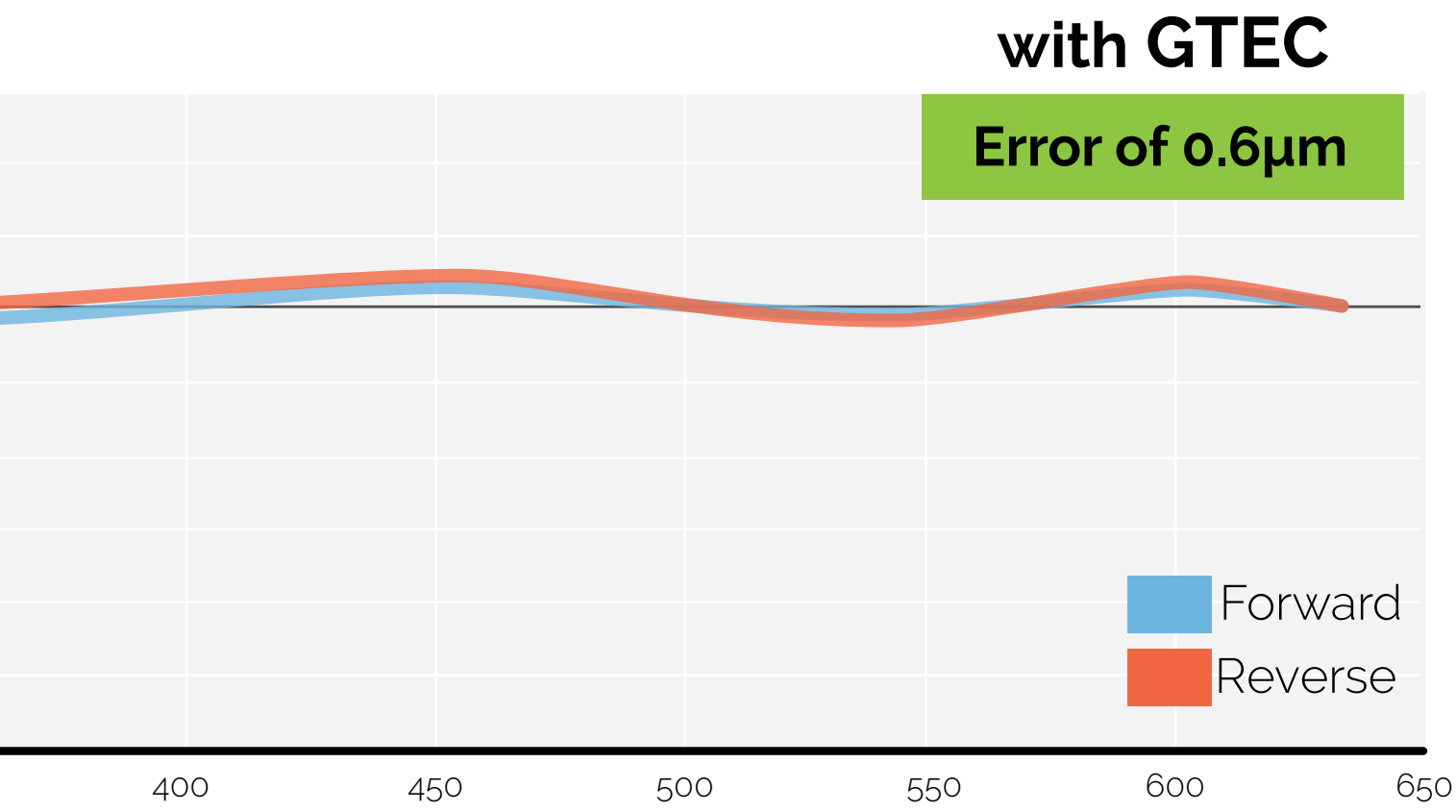
GEOMETRIC (VOLUMETRIC) - TYPICAL LINEAR COMPENSATION (Z-AXIS)





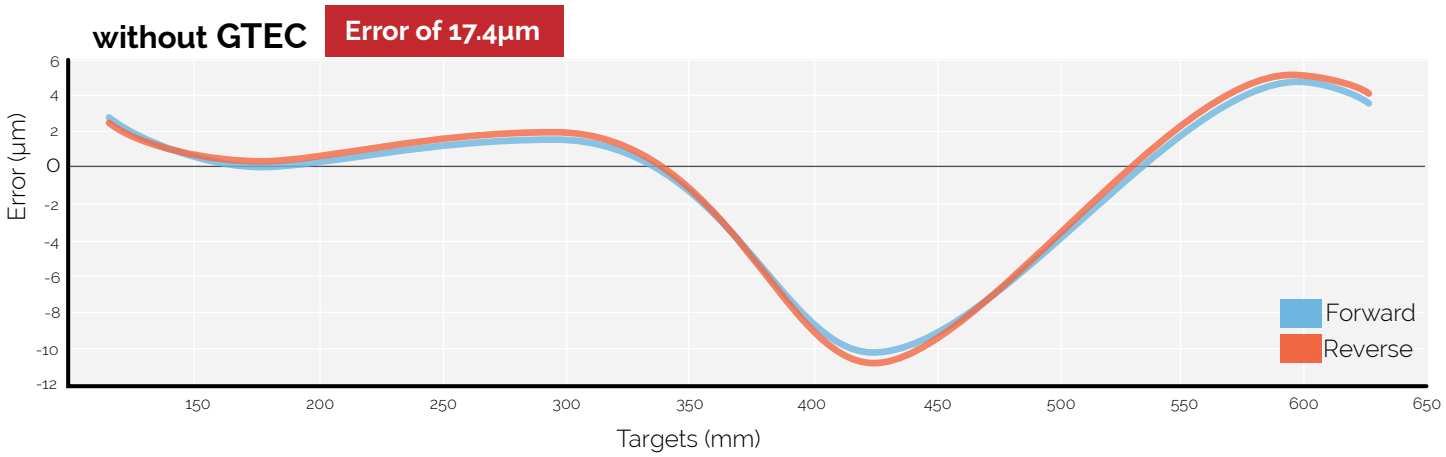
Uncompensated the error is 16.4µm and exhibits a profile influenced by the guideway pinning. **With compensation the error is reduced to 0.6µm**

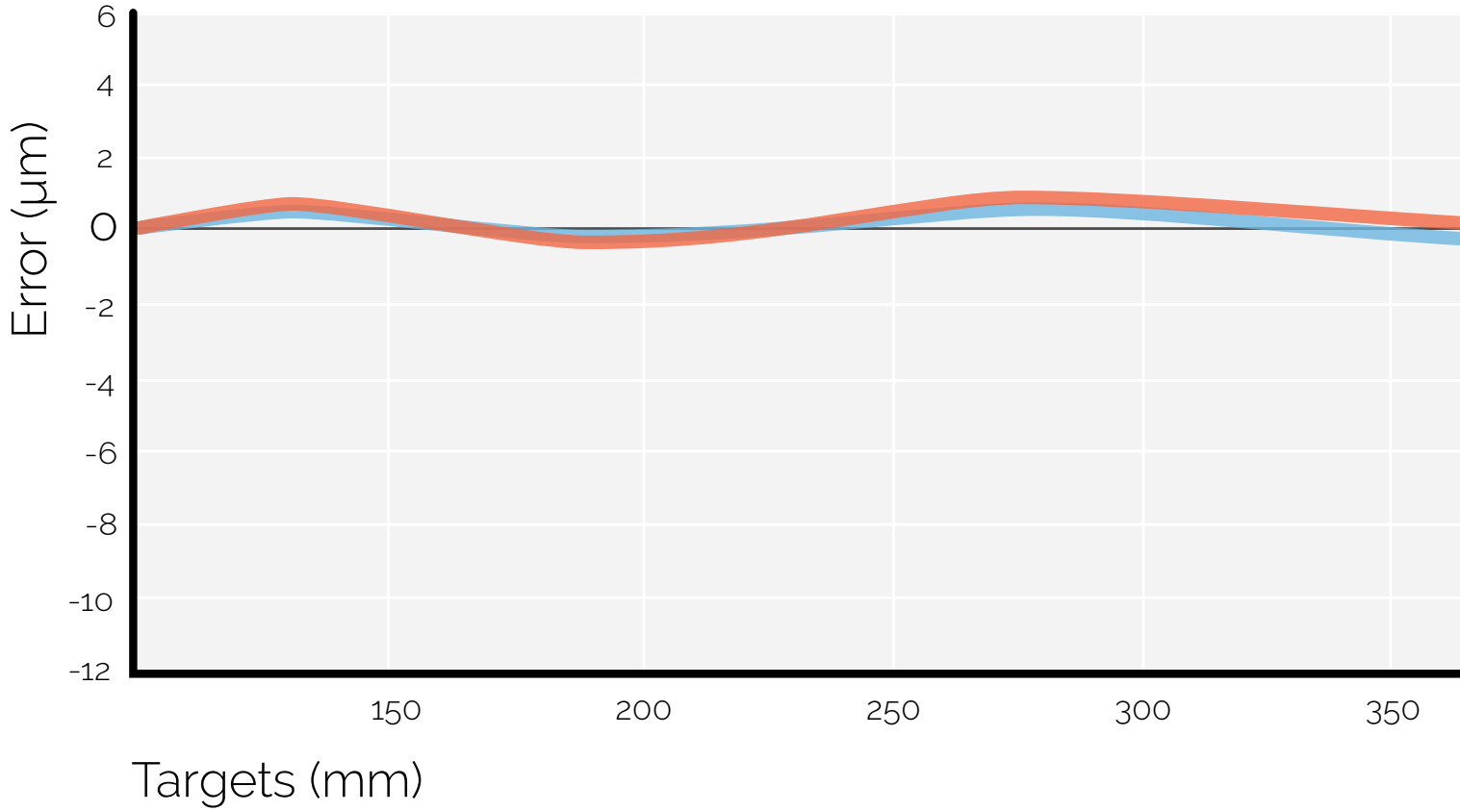
The results displayed below show the maximum level of compensation DAPATECH has achieved so far



GEOMETRIC (VOLUMETRIC) TYPICAL STRAIGHTNESS (Z IN X)

Straightness compensation is more difficult than linear compensation because it requires a stationary axis to overcome inertia. This performance can only be achieved if the compensated axis has sufficiently good electrical and mechanical control.

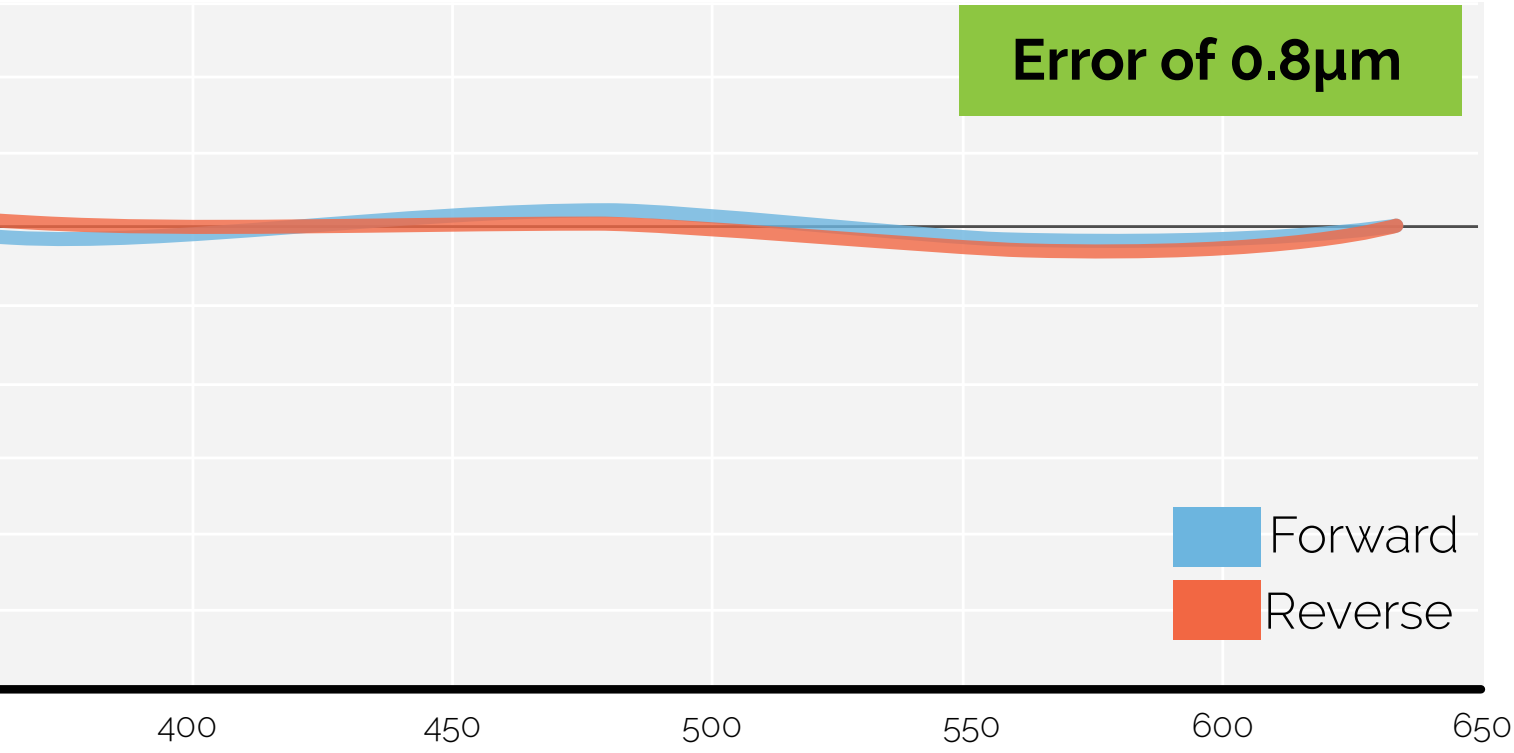




The straightness error has a total range of 17.4µm before **compensation and has been reduced to as small as 0.8µm after the compensation**

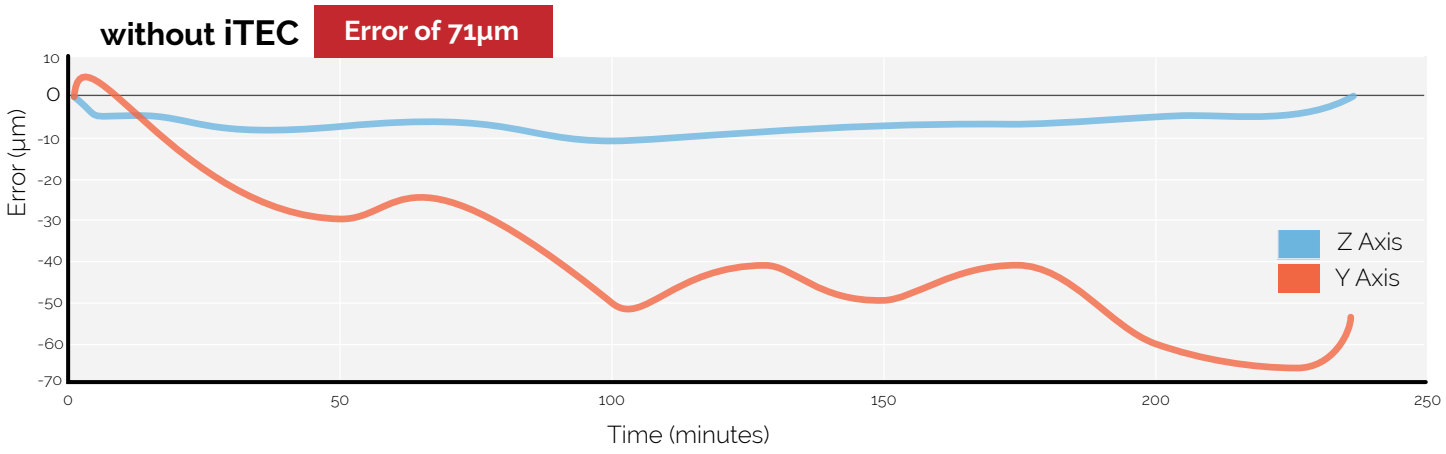
The results displayed below show the maximum level of compensation DAPATECH has achieved so far

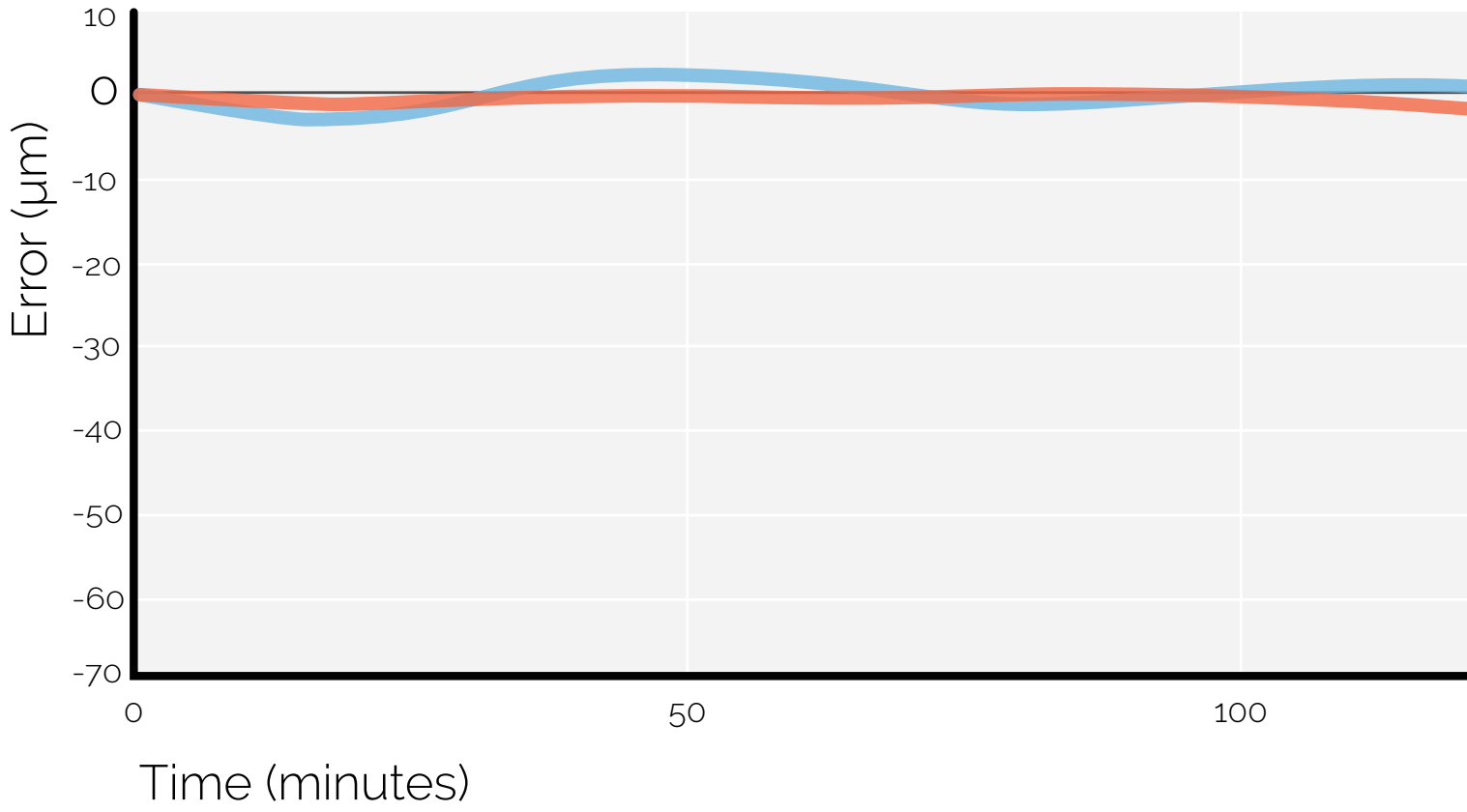
with GTEC



SPINDLE HEATING THERMAL COMPENSATION TEST

Random duty cycle spindle heating test.

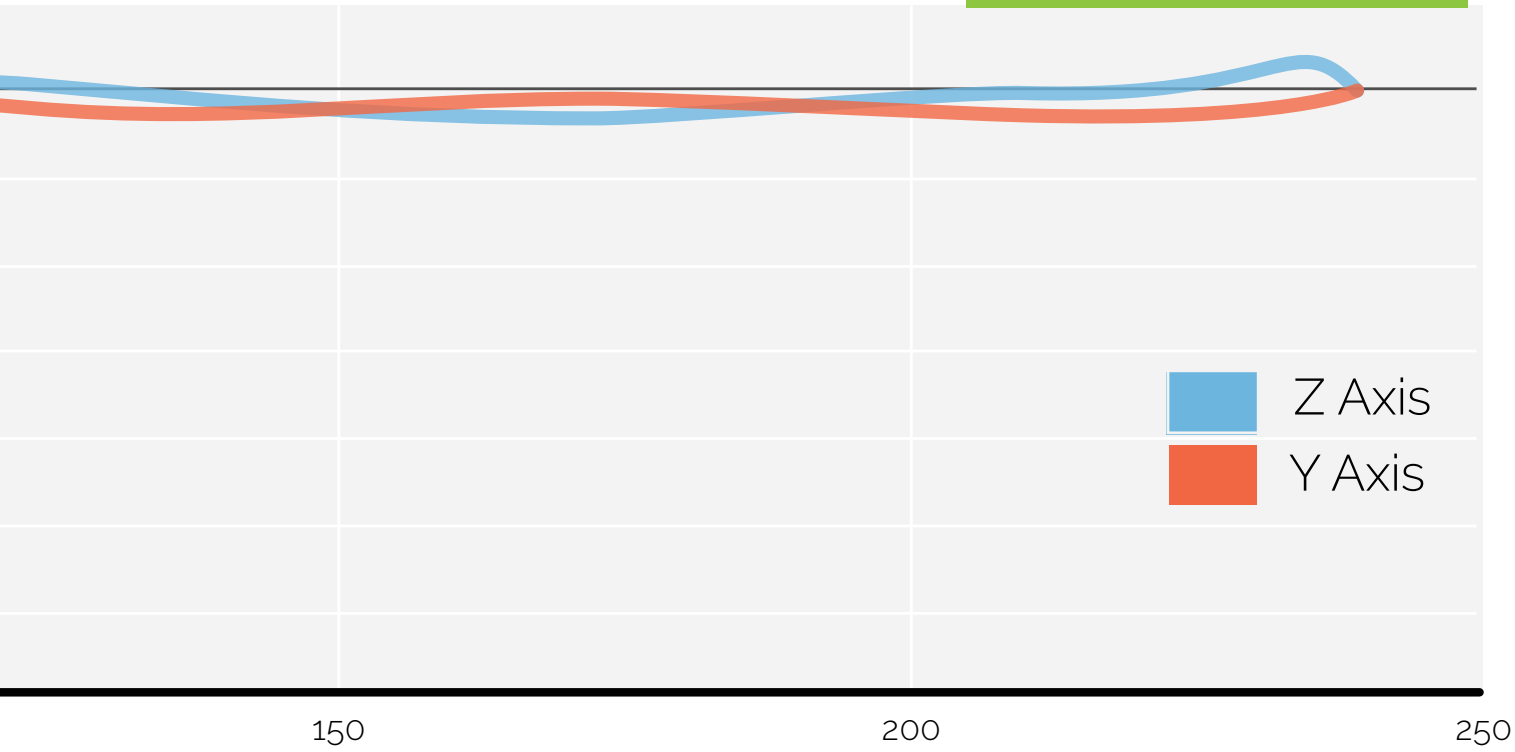




Position independent thermal errors in Y axis reduced **from 71µm to 7.5µm or approx 90%** Z axis reduced **from 14µm to 3.5µm or approx 75%**

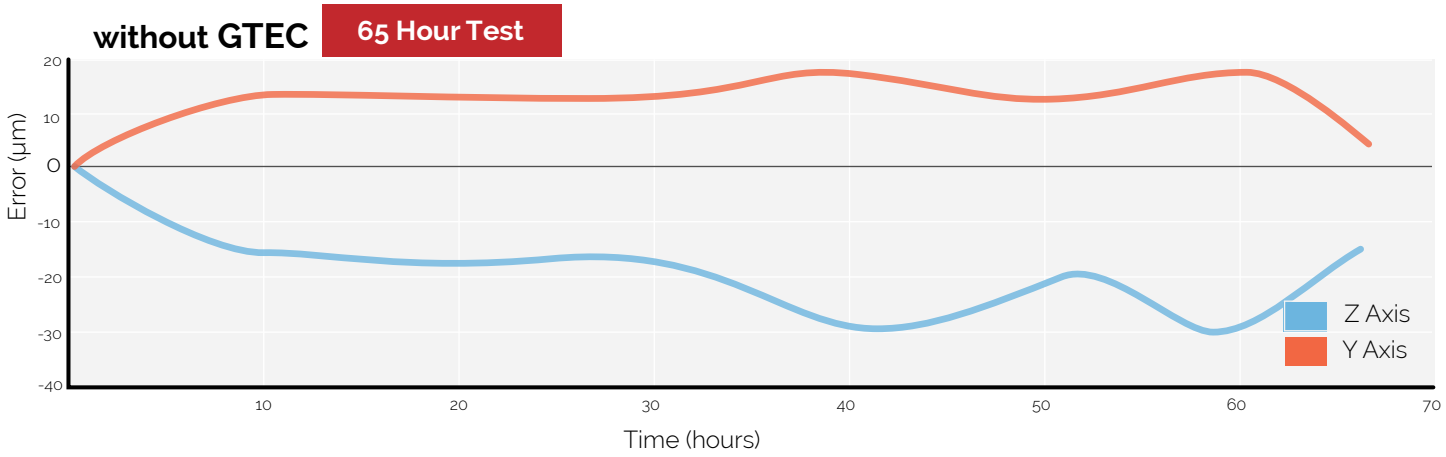
The results displayed below show the maximum level of compensation DAPATECH has achieved so far

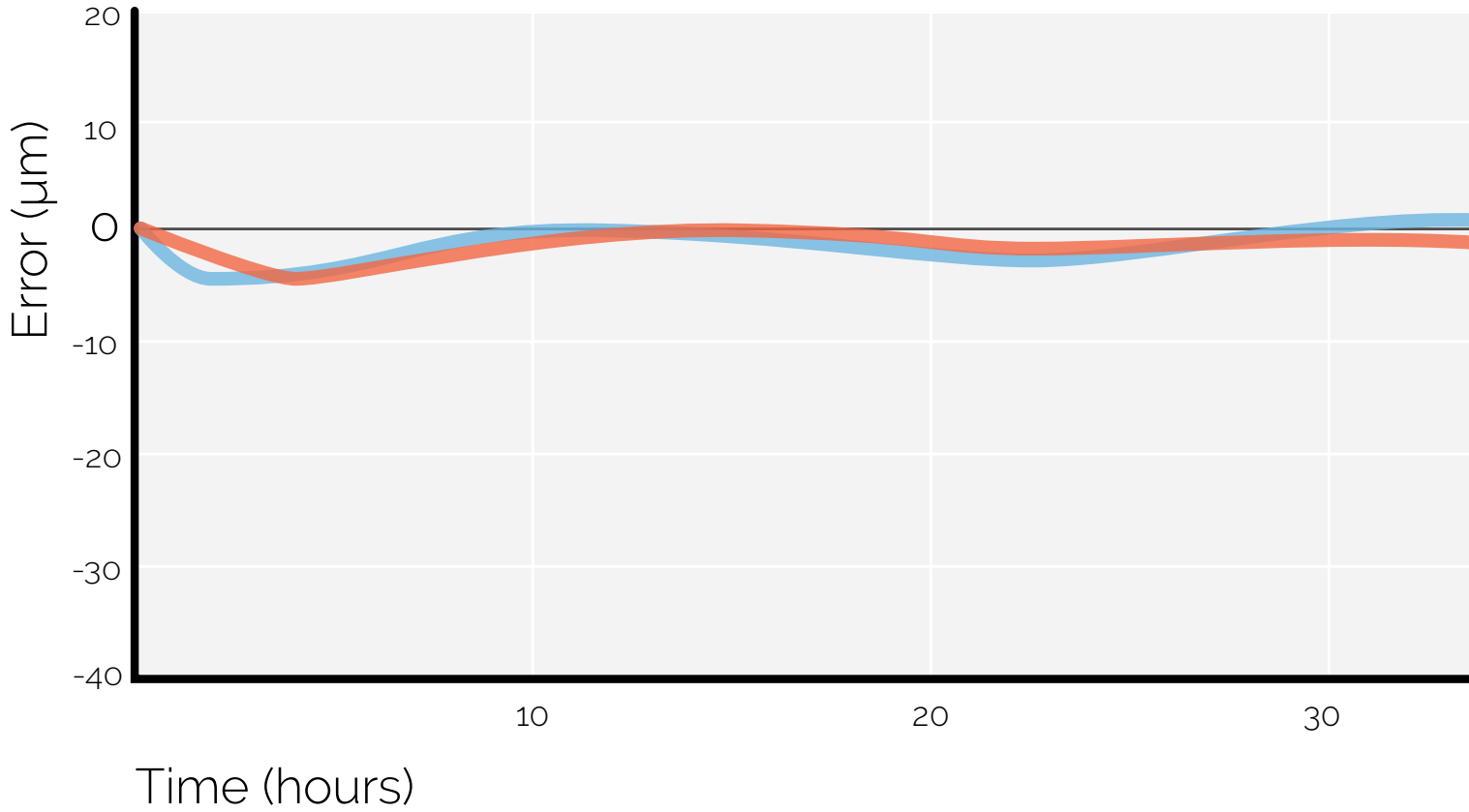
with iTEC **Error of 7.5µm**



ENVIRONMENTAL COMPENSATION

The recorded residual errors were mainly from rapid changes in air temperature. For test purposes the environment temperature was changed quickly, this creates lag in monitoring. These anomalies do not occur in a regular factory environment.



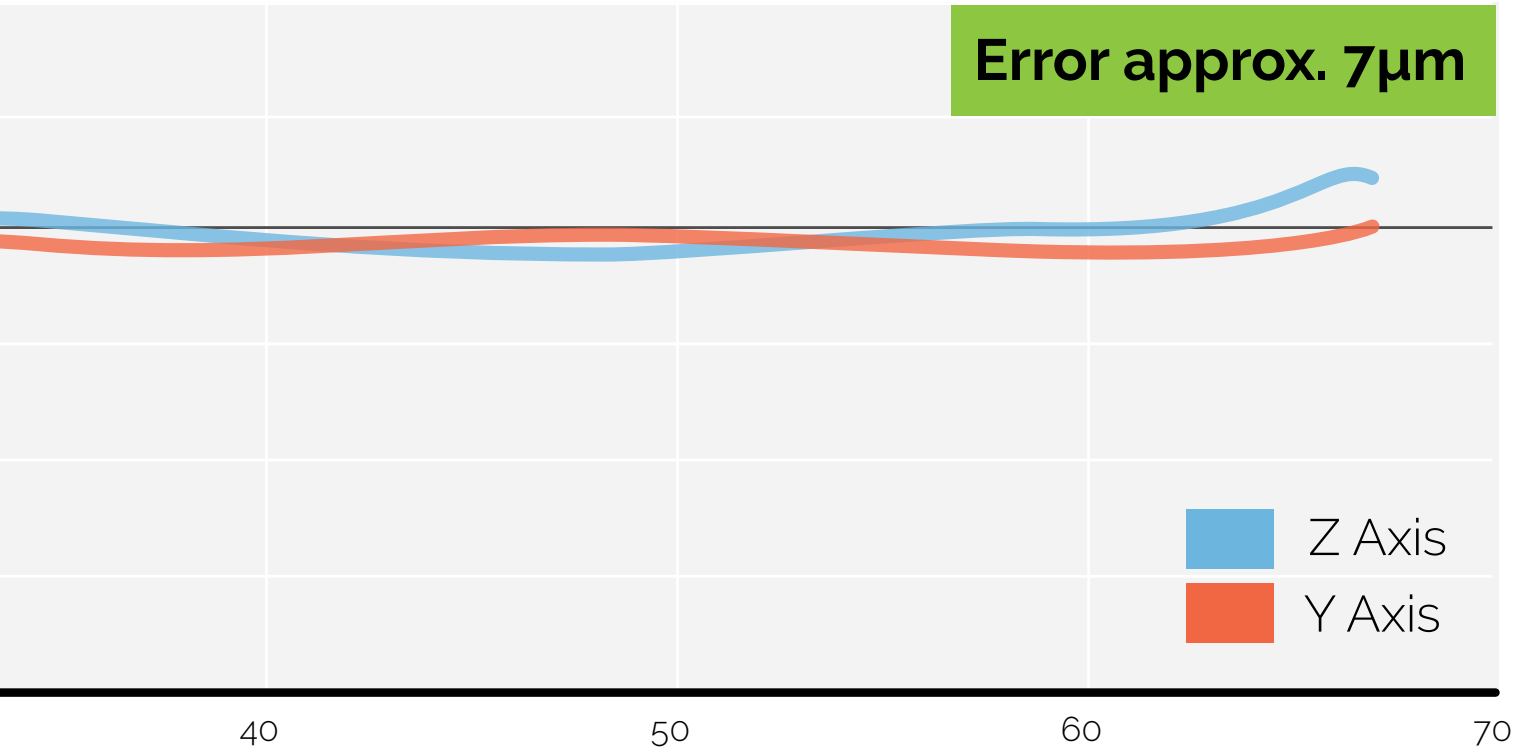


Extended environmental test resulting in **substantial compensation to approximately 7µm over a 65 hour test.**

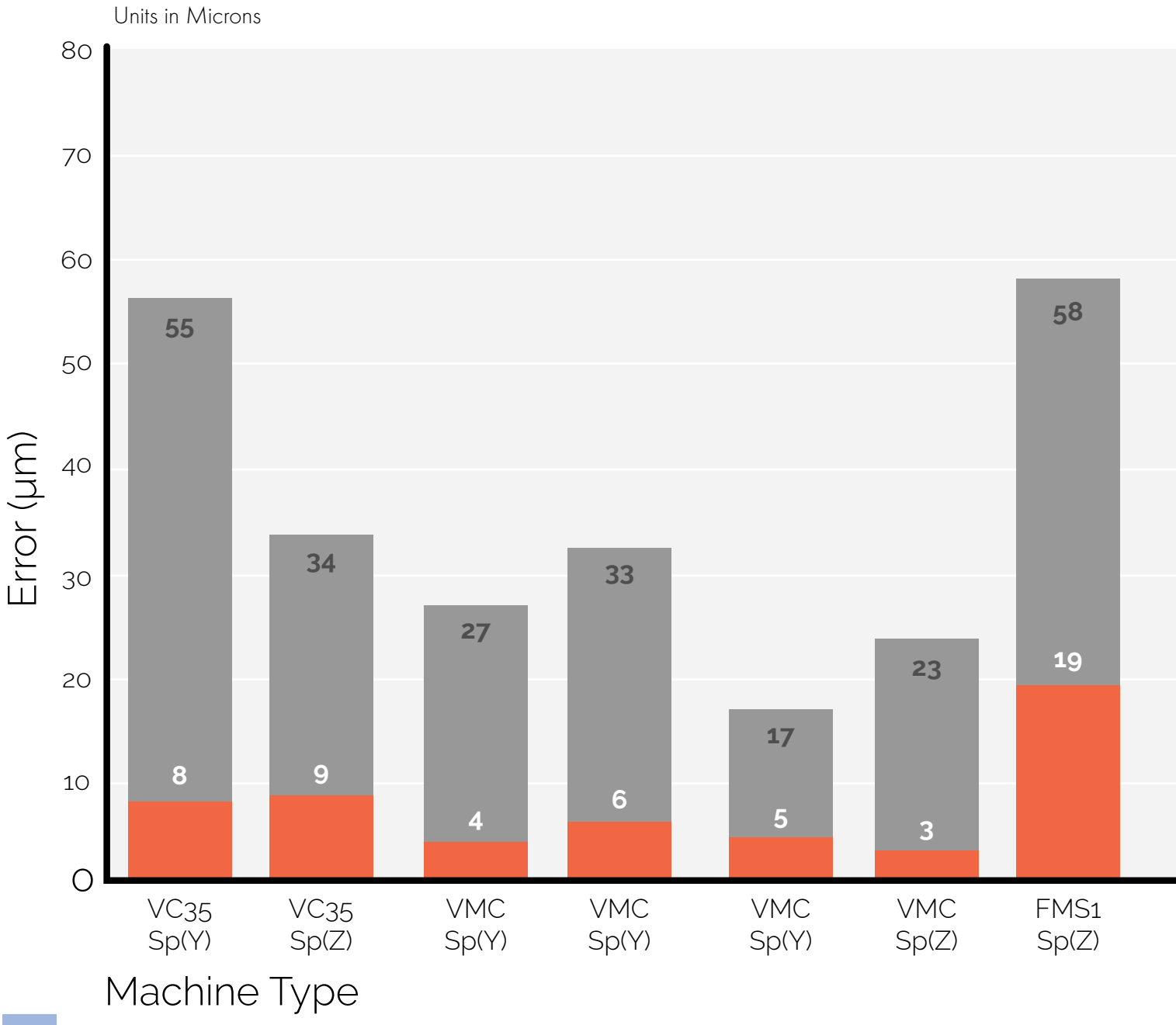
Residual errors mainly occur where rapid changes in air temperature occur.

The results displayed below show the maximum level of compensation DAPATECH has achieved so far

with GTEC

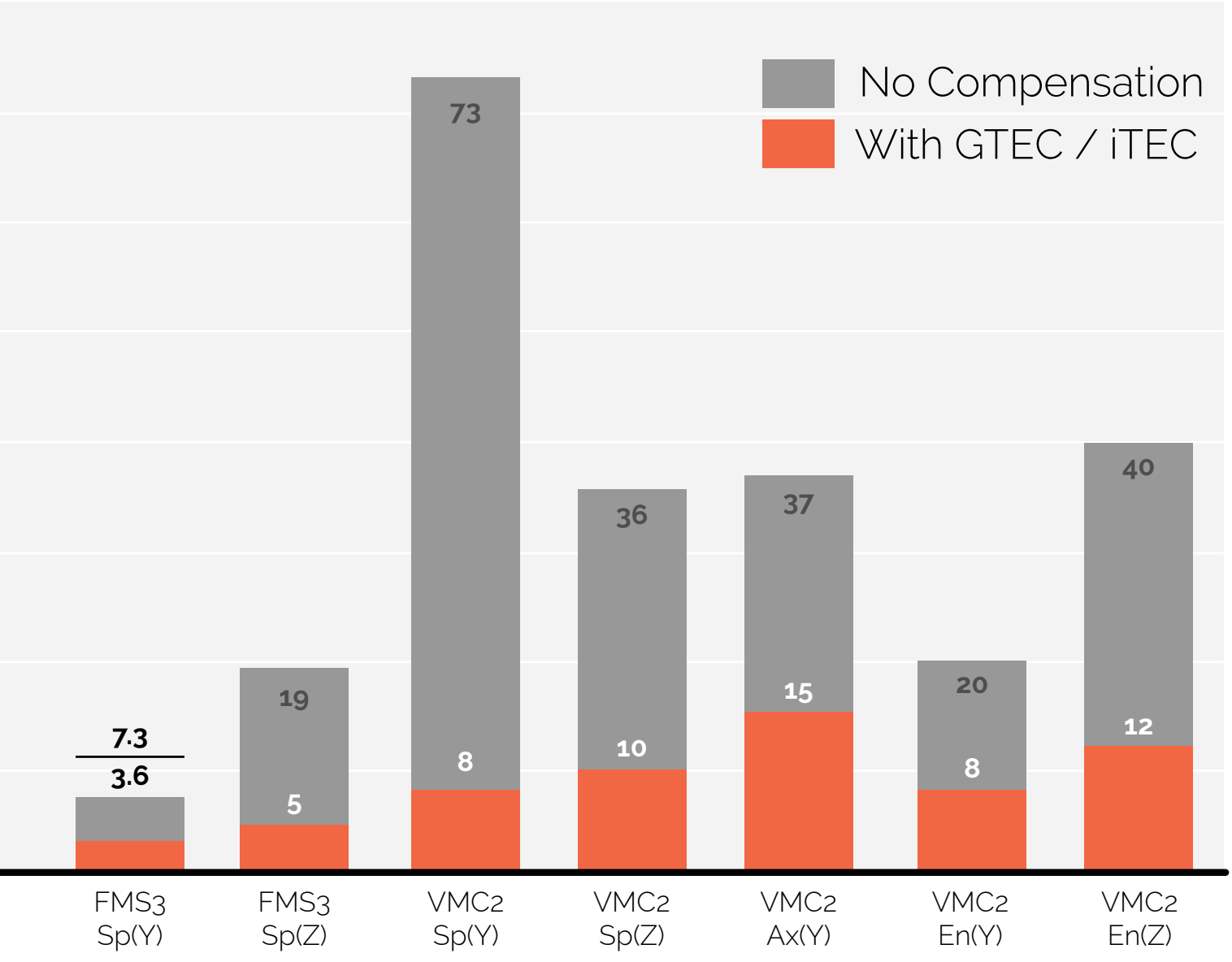


TYPICAL THERMAL COMPENSATION IMPROVEMENTS WITH GTEC & iTEC



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

The results displayed below show the maximum level of compensation DAPATECH has achieved so far



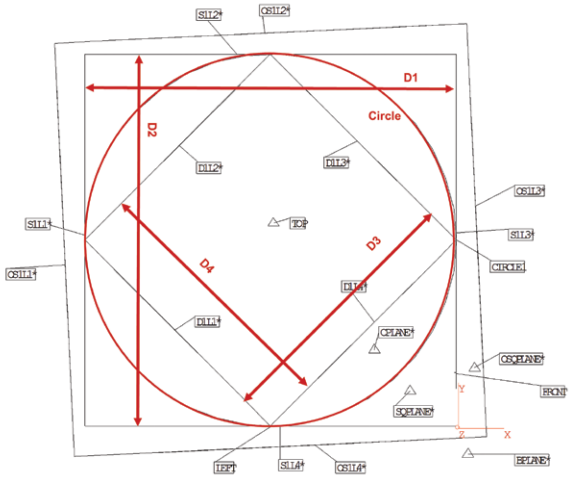
NAS CUTTING TEST RESULTS WITH GTEC

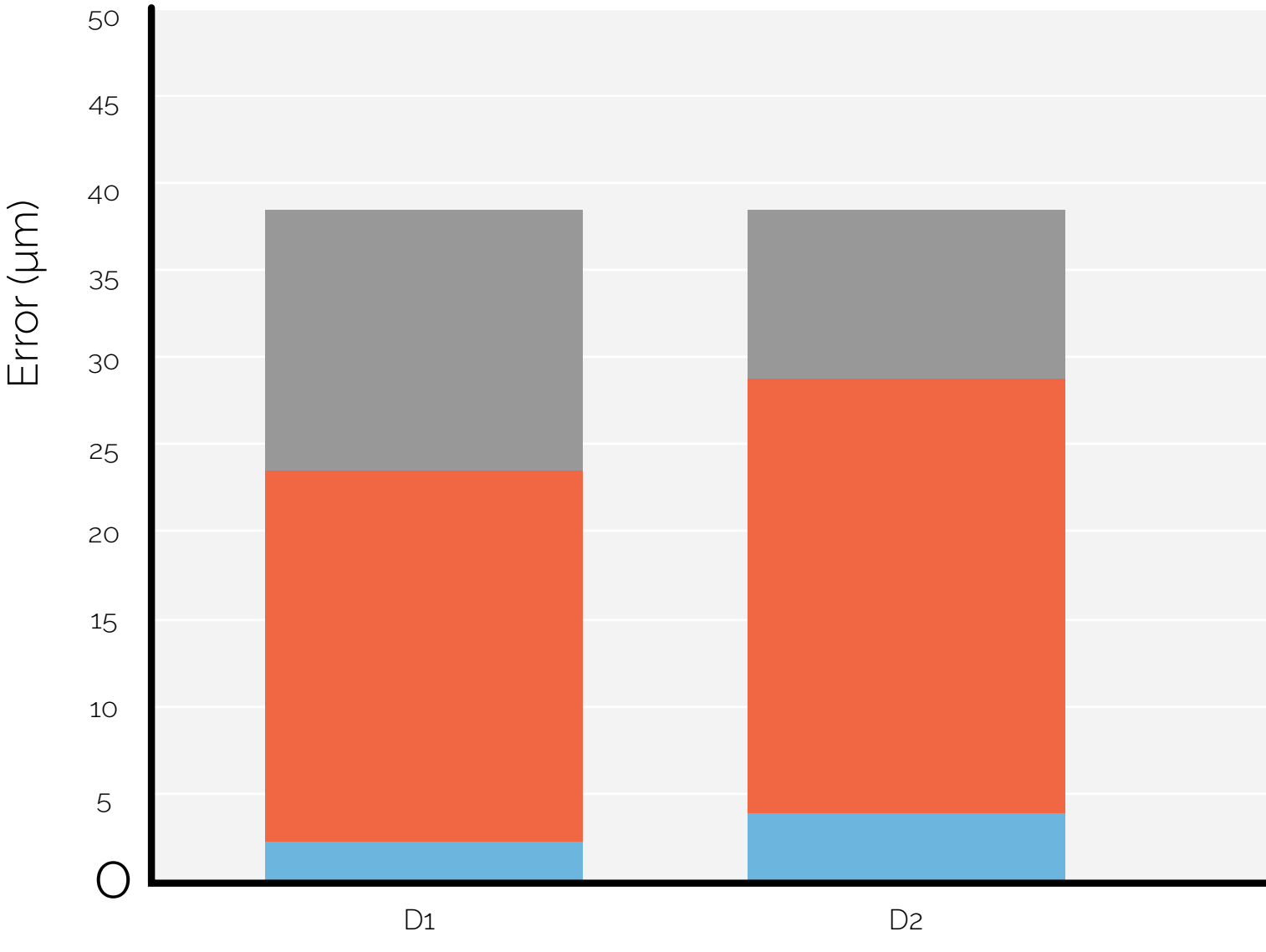
All 3 pieces were machined in similar environmental conditions with an ambient temperature of 25ºC (77ºF). The thermal effect on the machine can clearly be observed and the compensation was very successful. Average feature improvement on test dominated by high workshop temperature.

Test pieces manufactured and measured on a CMM

Some representative dimensions are presented

- Size of square
- Size of diamond
- Diameter of circle

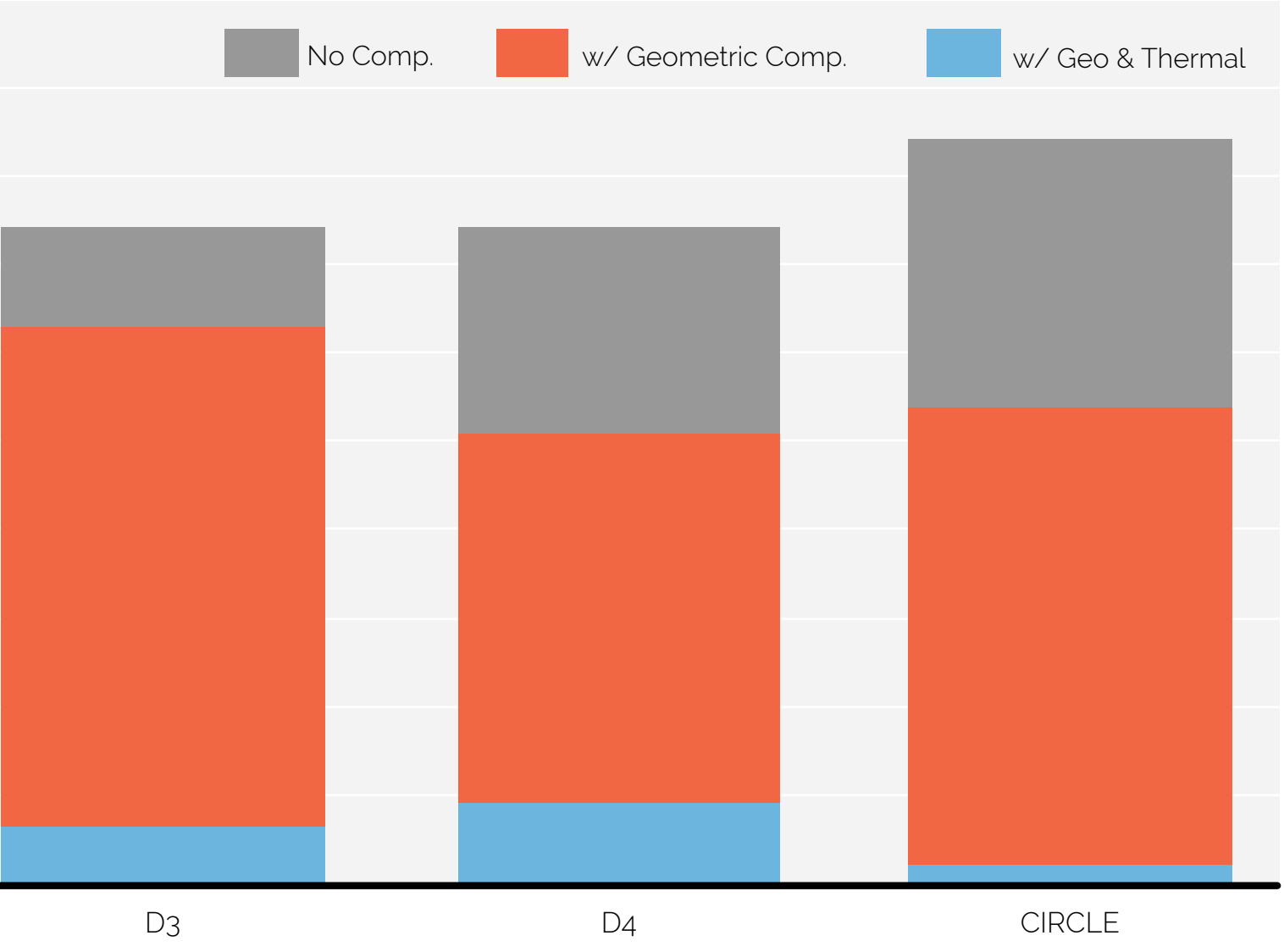




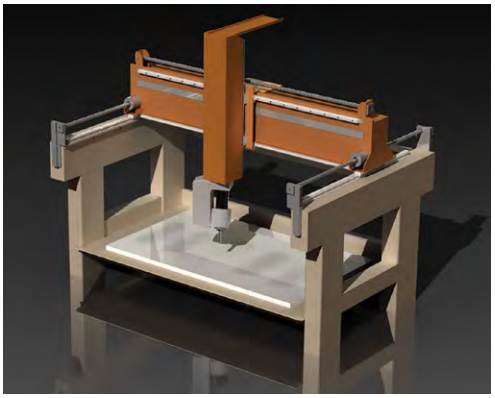
40%
improvement
With Geometric (volumetric) Compensation

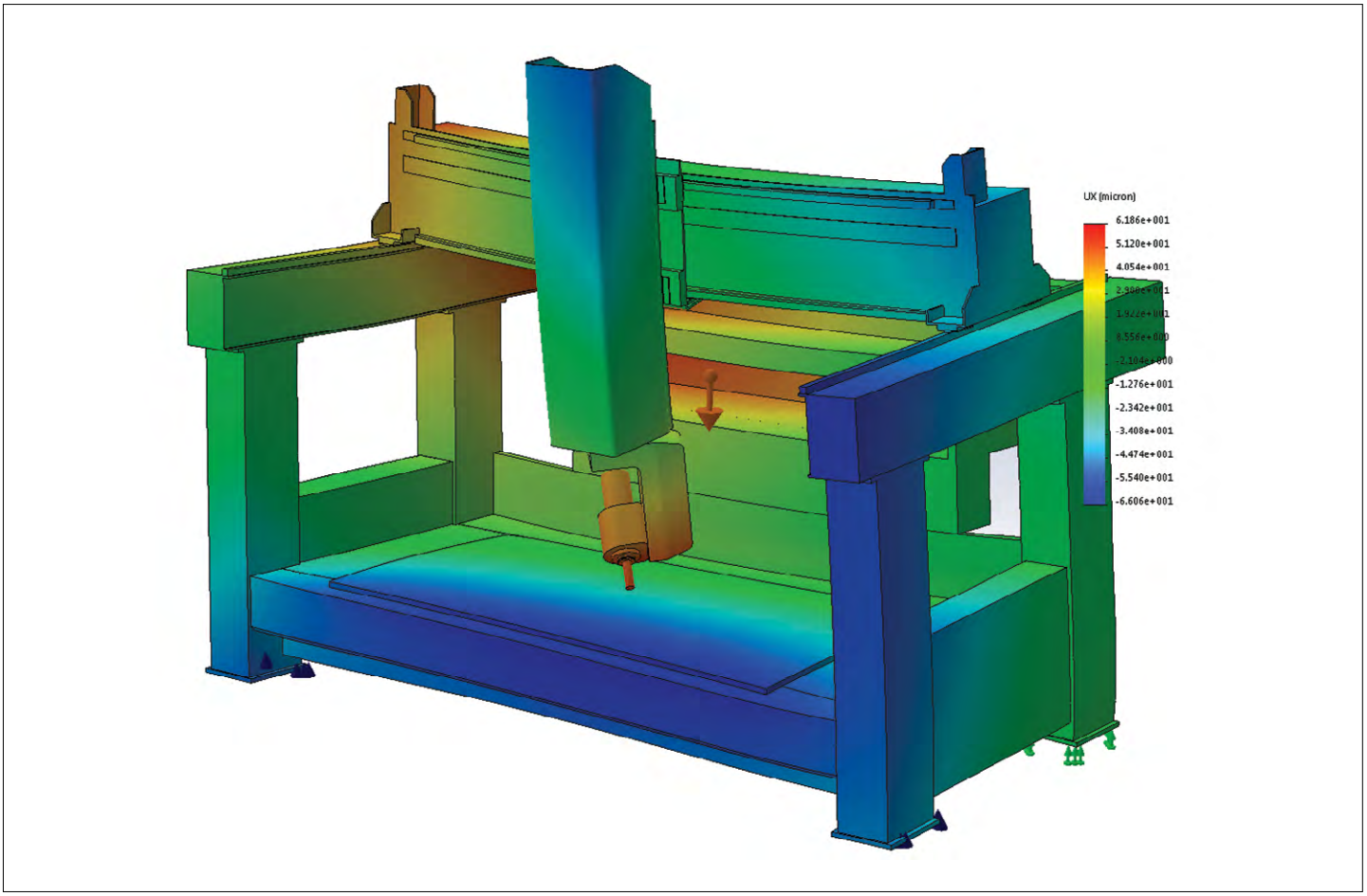
92%
improvement
With Geometric (volumetric) and Thermal Compensation

The results displayed below show the maximum level of compensation DAPATECH has achieved so far



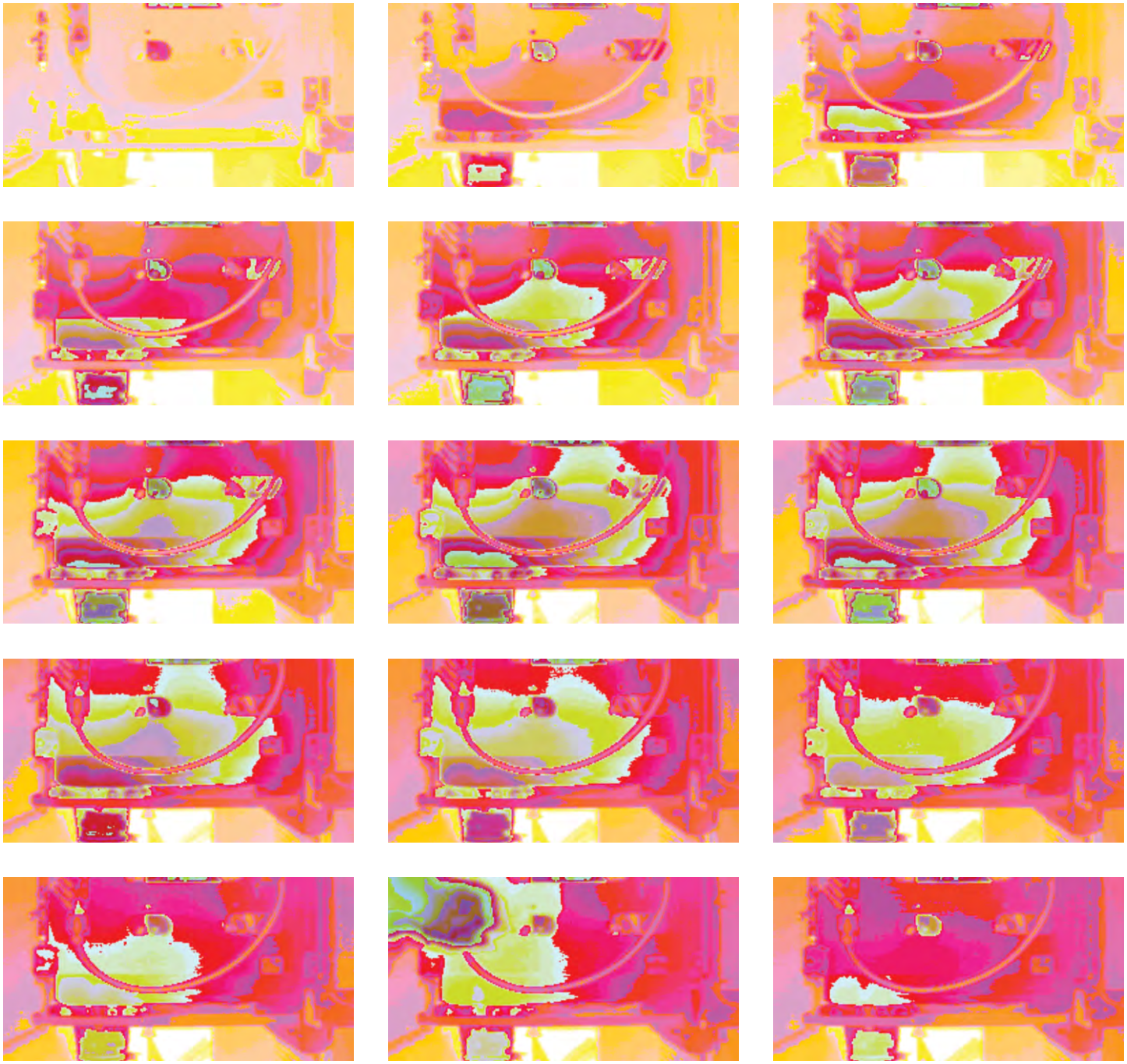
SIMULATING MACHINE DISTORTION





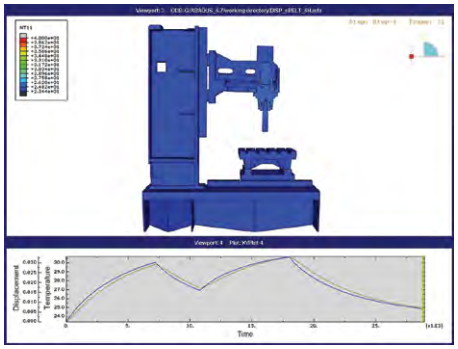
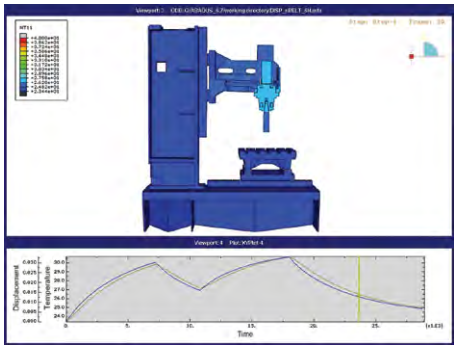
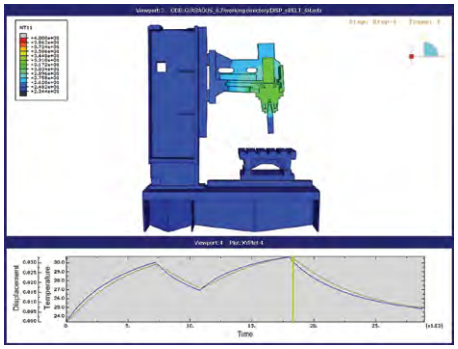
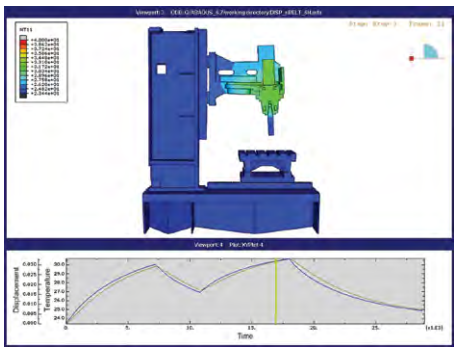
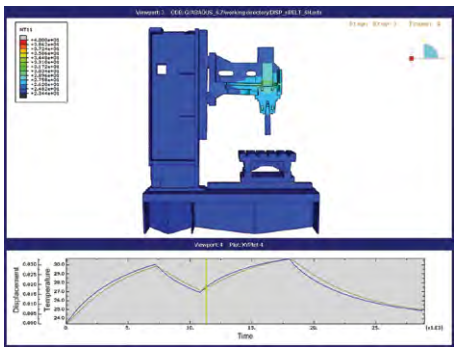
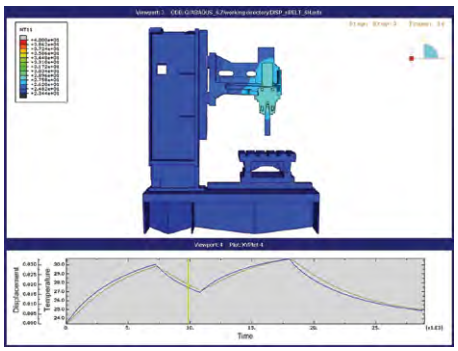
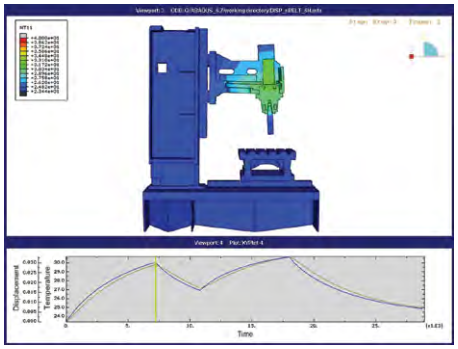
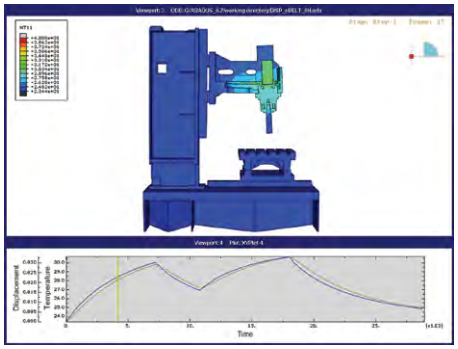
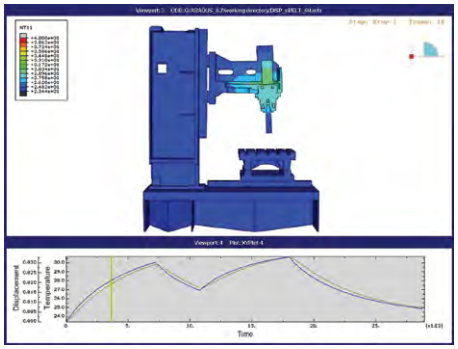
SPINDLE HEAT THERMAL VIEW

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

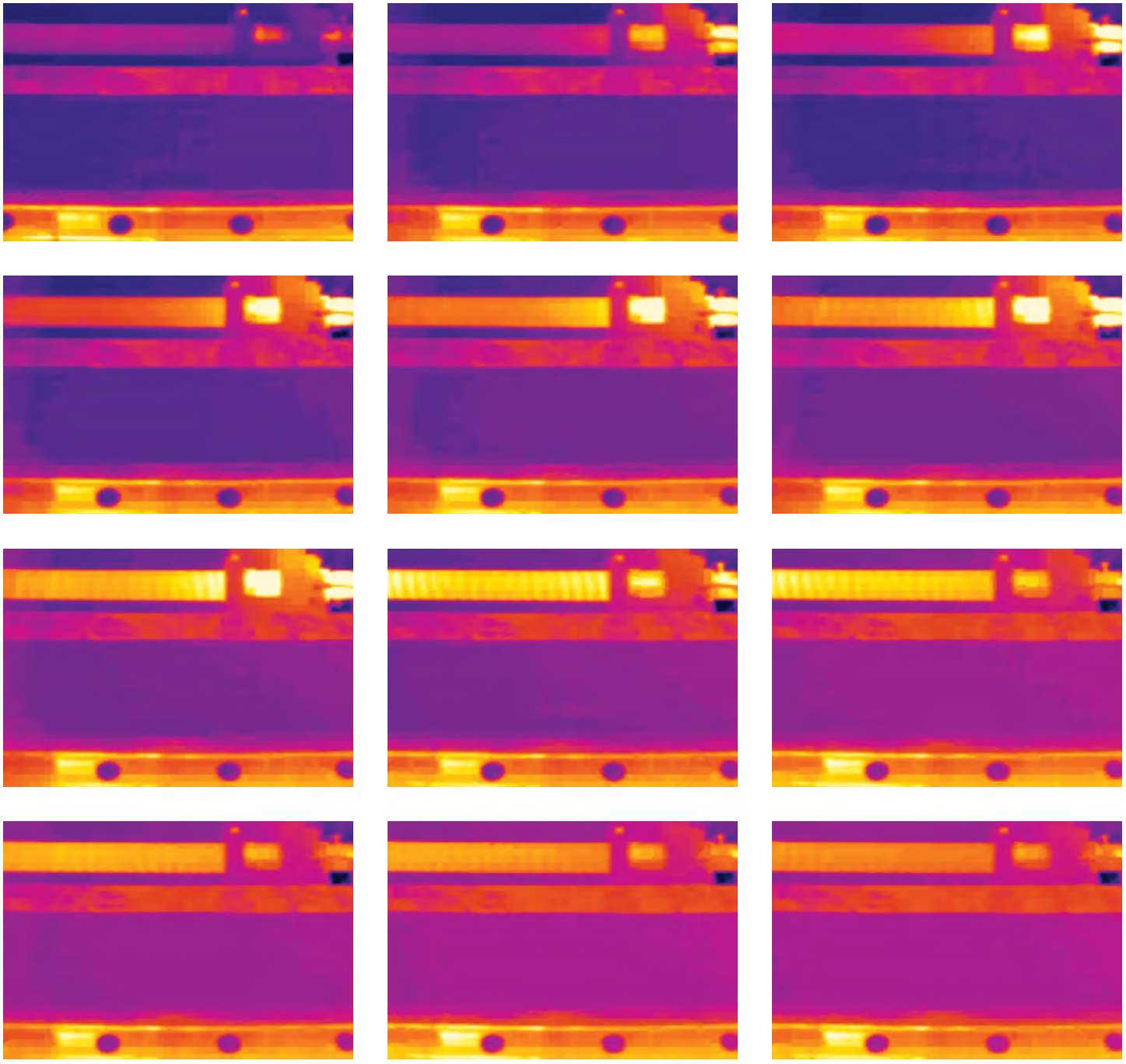


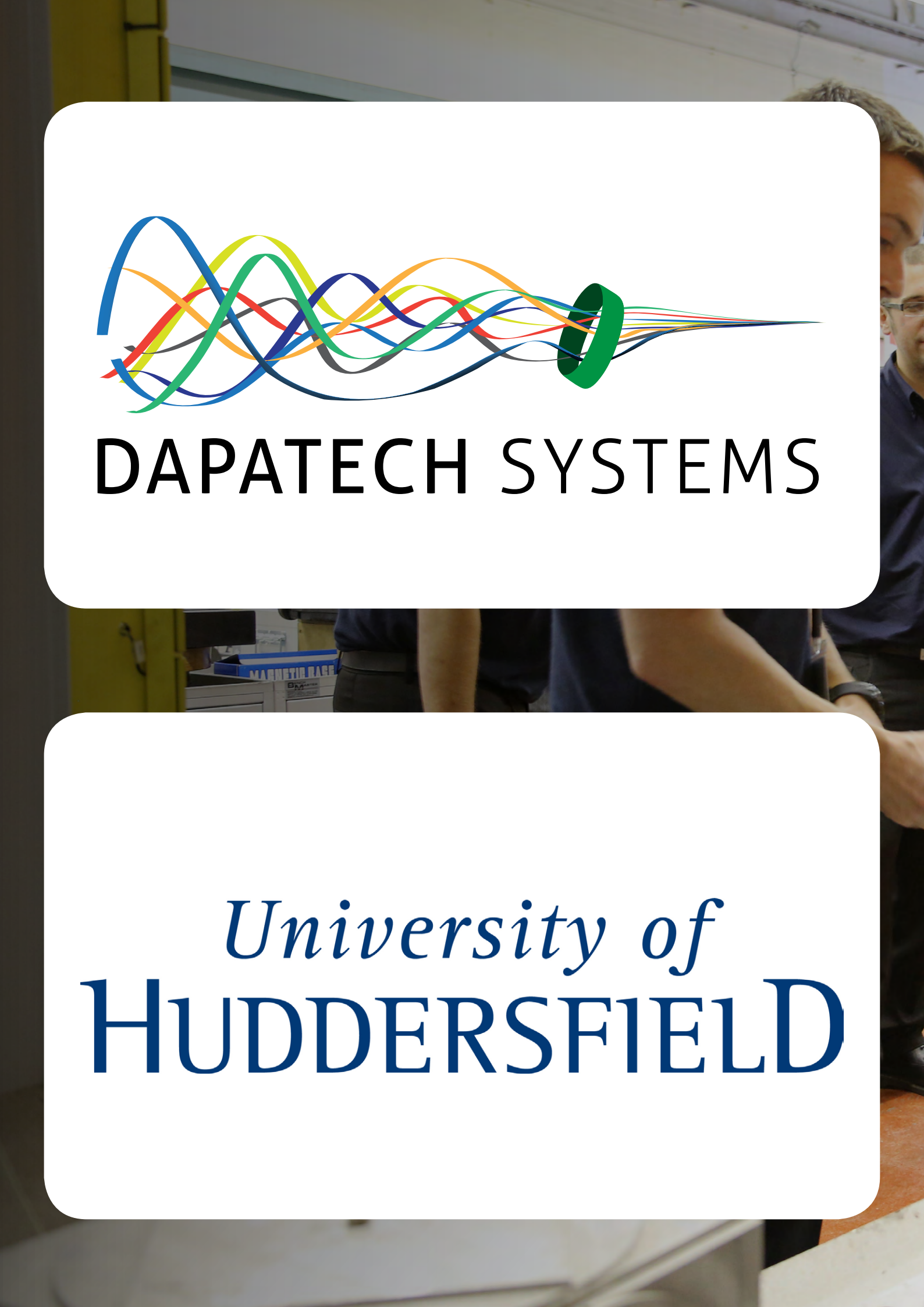
SPINDLE HEATING THERMAL EFFECT

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

SLIDE WAY & BALL SCREW THERMAL VIEW





DAPATECH SYSTEMS

University of HUDDERSFIELD

The GTEC & iTEC systems have been developed by DAPATECH in partnership with the University of Huddersfield

MORE ON GTEC & iTEC

GTEC & iTEC IMPLEMENTATION METHODS

DAPATECH GTEC & iTEC are available as either an incremental or absolute system.

Currently there are two ways to implement GTEC or iTEC:

1. Through a GTEC Main Interface Box (DAPATECH GTEC Box) integrated in the position feedback loop of all the axes. This is an 'incremental' system.

2. Through a GTEC or iTEC Mini Box setup that will compensate by manipulating data within the CNC controller, e.g. on a Fanuc Robodrill with 31i controller. This is an 'absolute' system.

DAPATECH GTEC BOX

In the 'incremental' system the pulse train of the encoders on each axis is intercepted by the compensation cards in the DAPATECH GTEC Box. After interception the error component for each axis is calculated.

Based on the current axis positions, measured error data, geometric and thermal models the compensation is applied by adding or subtracting edges to or from the pulse train that is sent out by the compensation cards.

This entire process is executed without interfacing with the controller.

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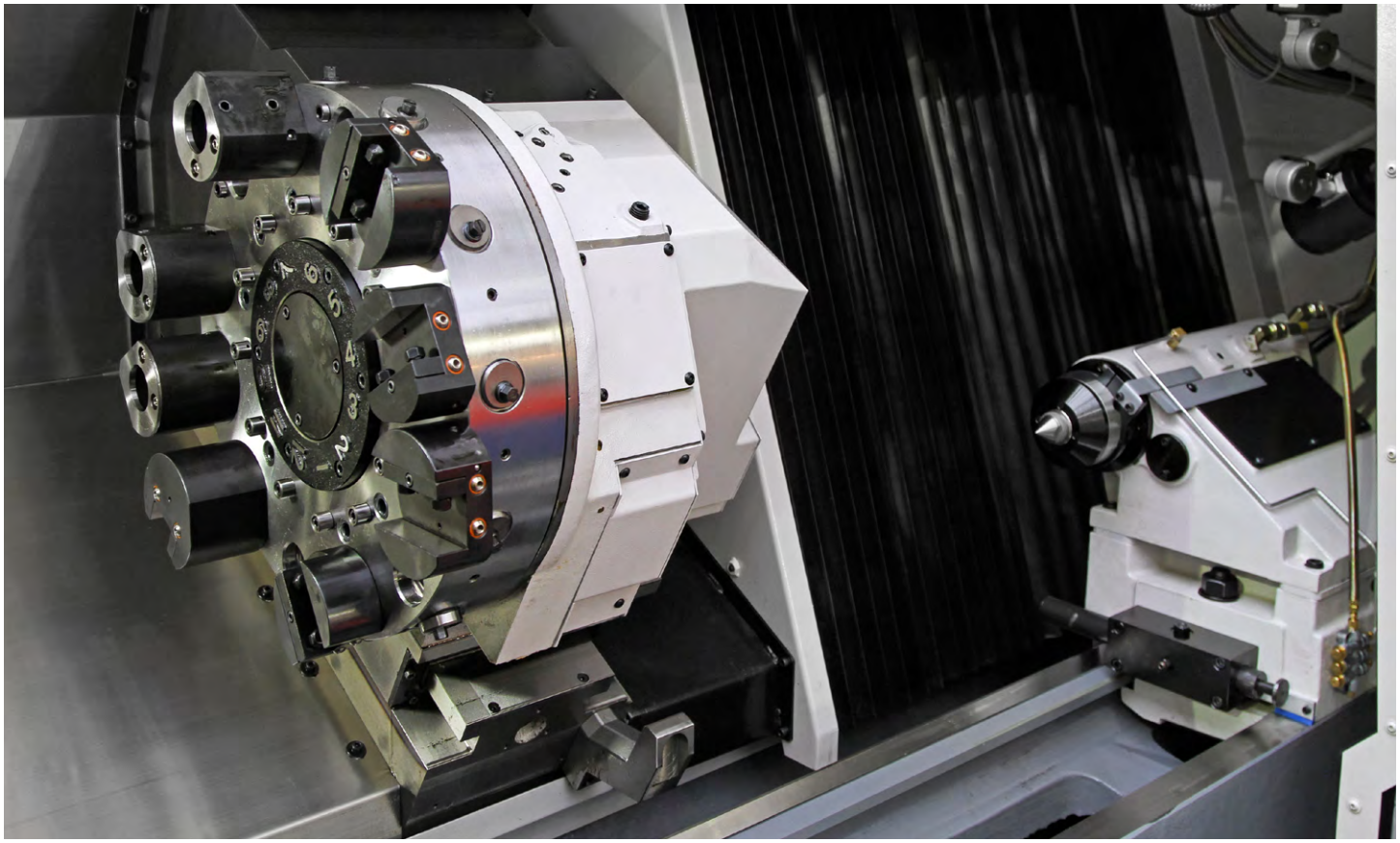
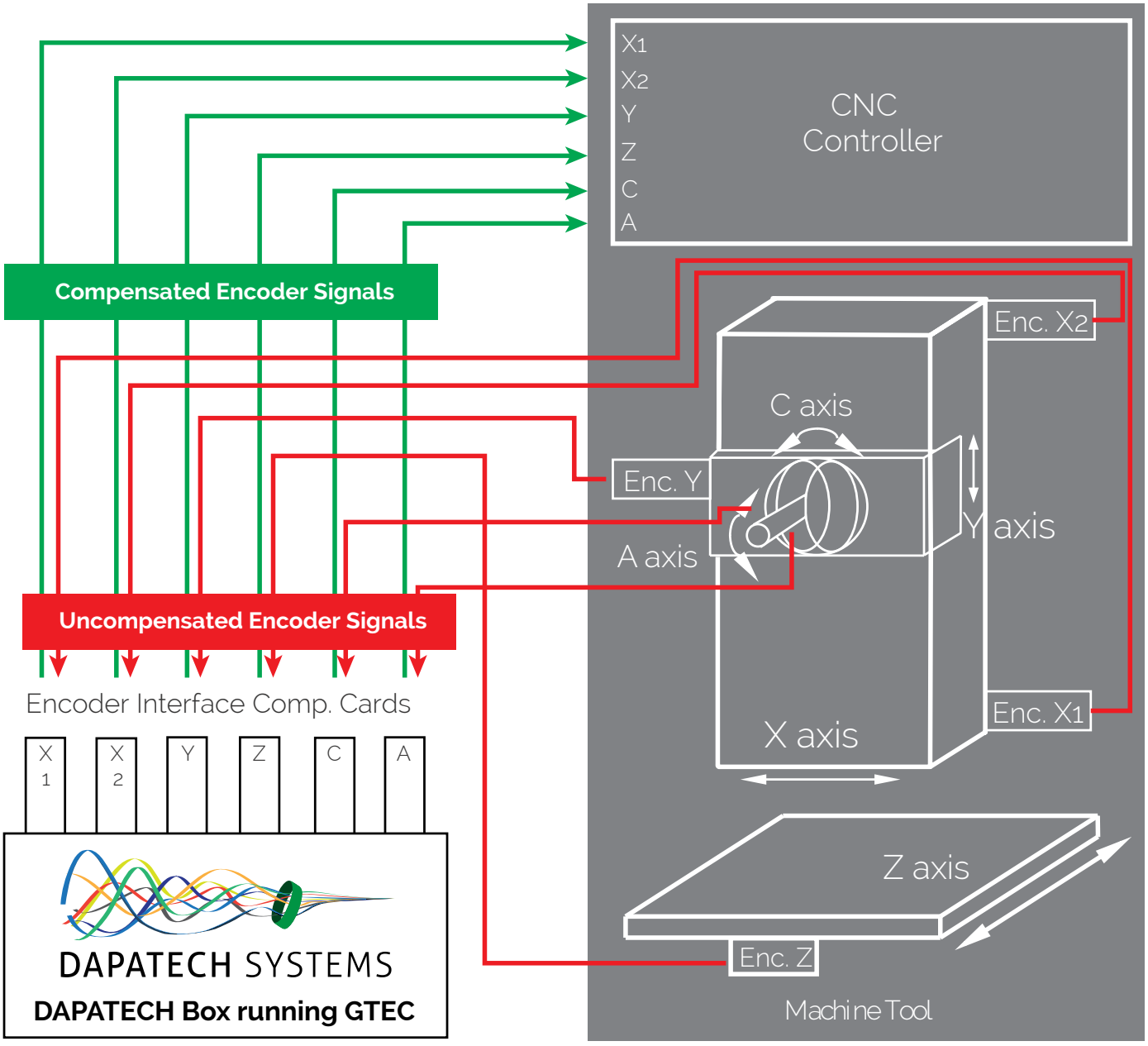


DAPATECH GTEC Box Schematic

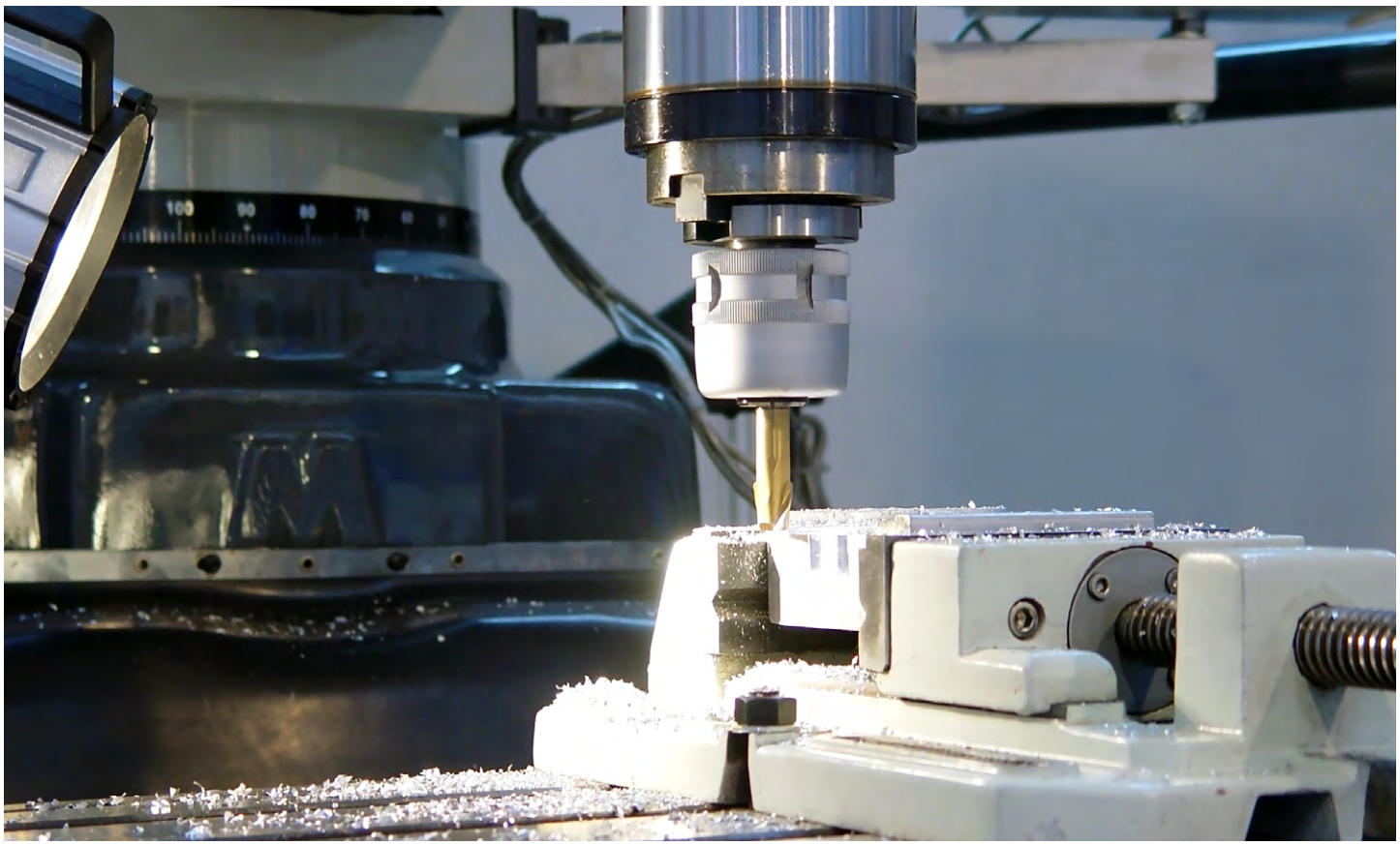


DAPATECH GTEC OR iTEC MINI BOX

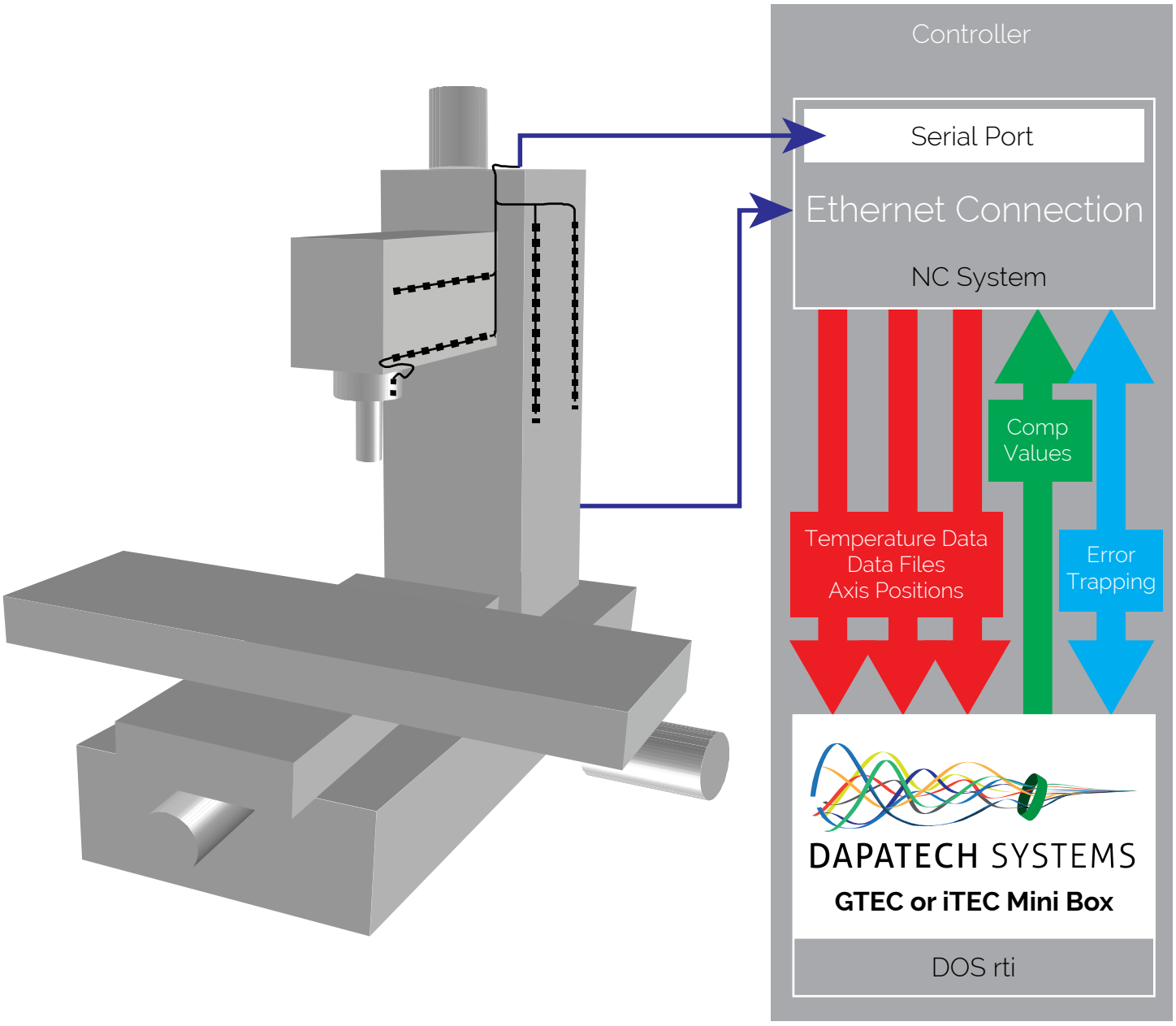
In the 'absolute' system the absolute position is read directly from the controller by the DAPATECH GTEC or iTEC Mini Box via a serial (e.g. ethernet) connection.

Subsequently the error component for each axis is calculated based on the current real time axis positions, measured error data, and the geometric and thermal models.

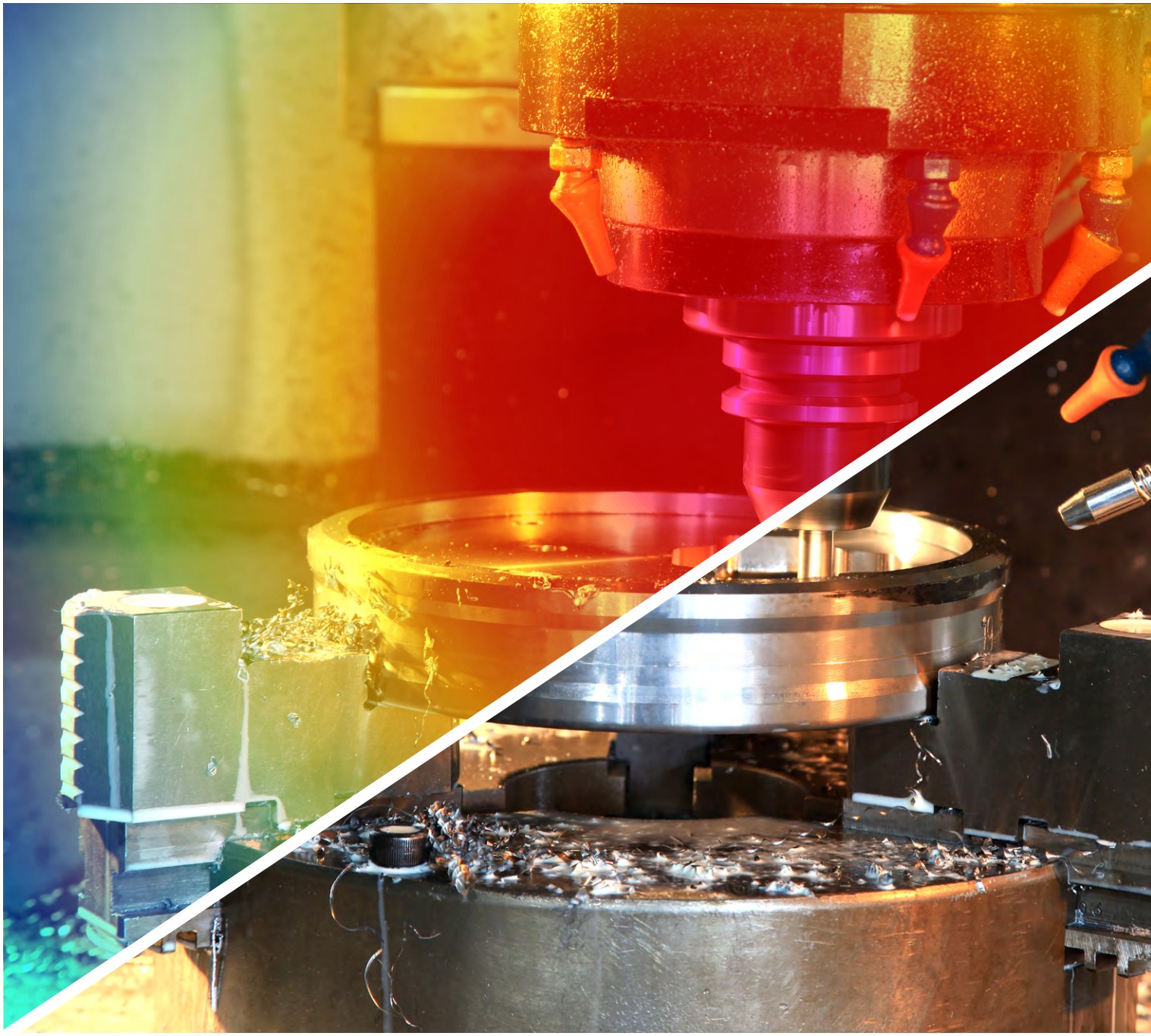
In the 'absolute' system the absolute position is read directly from the controller

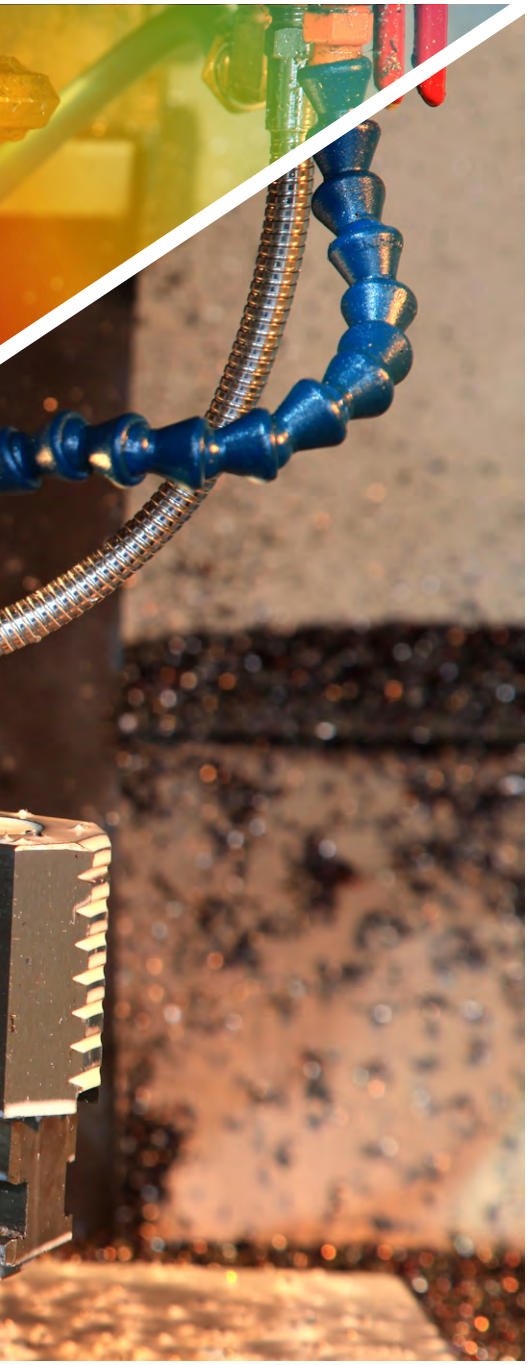


DAPATECH GTEC or iTEC Mini Box Schematic



MORE ON THERMAL COMPENSATION WITH GTEC AND iTEC



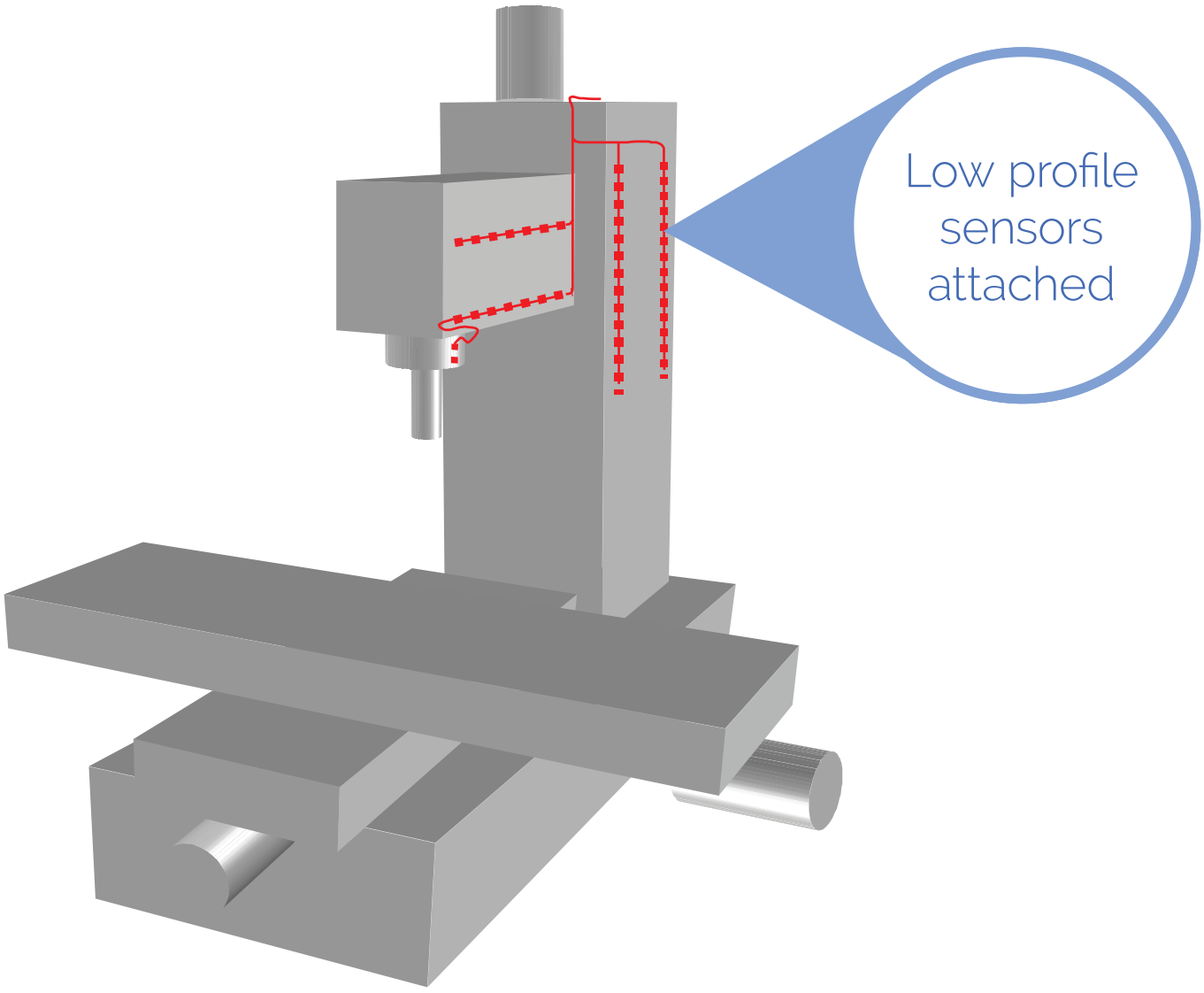


The thermal compensation system can be customized to suit a particular machine.

The system is built such that it can accommodate a variable number of temperature sensors. The system's flexible programming approach allows for an implementation of a machine specific compensation model unique to each individual machine.

EXAMPLE OF THERMAL SENSOR LOCATIONS

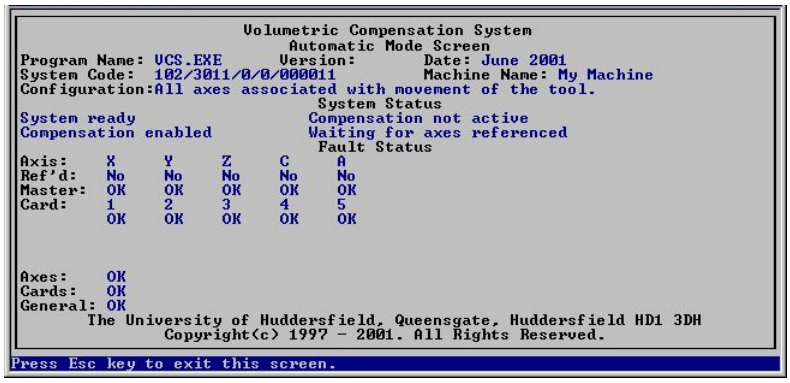
The sensors can be applied individually or in strips of multiple sensors.
The sensors have a low profile allowing them to be applied in confined areas.



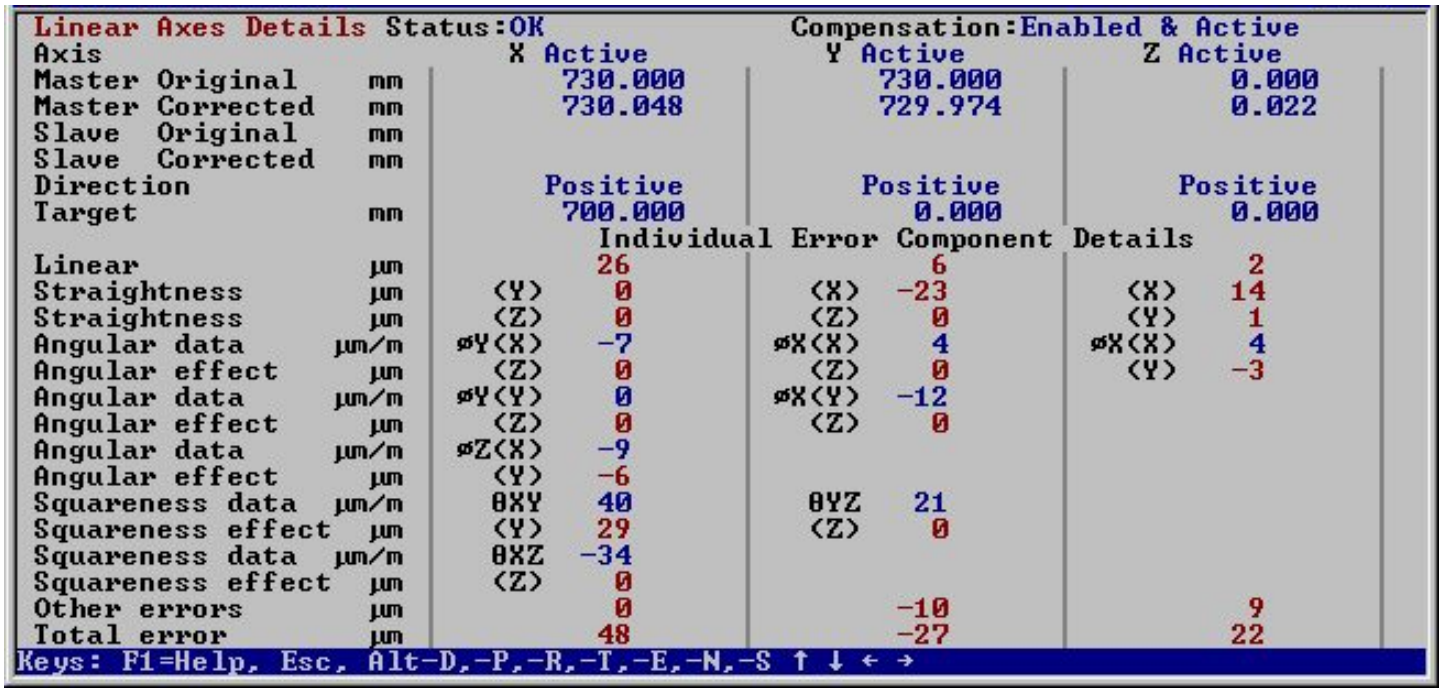
GTEC & iTEC MODE OF OPERATION AND OPTIONS

GTEC & iTEC can run in any of the following modes of operation:

- Automatic or 'auto mode' (normal operation mode)
- Manual (typically used during installation, recalibration or for data input)
- Compensation with display
- Diagnostics

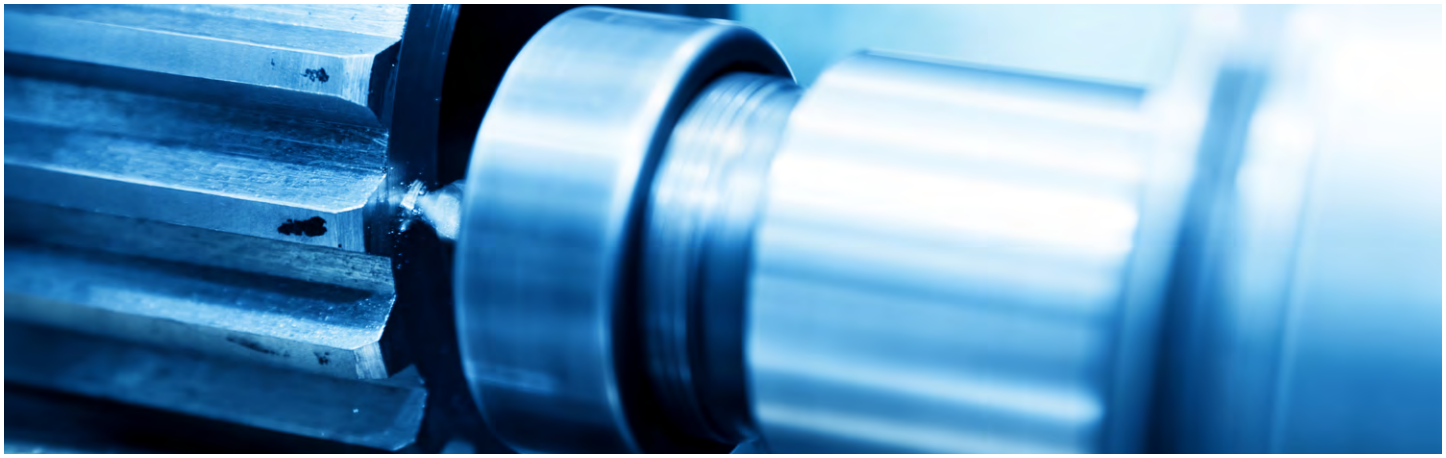


Example of 'auto mode'



Monitoring Compensation live on a display

MACHINE PROTECTION IN GTEC



The GTEC system is designed to work 'in the background' with no operator interaction while the machine is in operation.

The GTEC software ensures there is sufficient error trapping to monitor and consider any unexpected/ irregular event or alarm. When such an event or alarm occurs the GTEC system will suspend its operation in a controlled manner with stopped axes and the spindle in a safe position. The event or alarm is communicated to the CNC controller and will be displayed on the operator screen showing him the necessary information to take appropriate action. The machine is conditioned to allow for a safe reset and control of the machine.

The protection of the machine is ensured by the GTEC system integrity which allows for safety factors such as a parameter for each axis that sets a limit on the maximum permissible correction that can be applied.

A software 'watchdog' is included on the system to detect all and any fatal errors.

Additionally all actions are recorded to a log file. These include:

- GTEC system initialization sequence
- GTEC system activation or deactivation by external input (i.e. a physical switch)
- Any faults
- Any updates to parameters or data files

The visual diagnostic modes can be entered and used by any operator if needed but a password is required to access any screen where system input (parameters or data files) can be changed. This is to ensure access is only permitted to trained and authorized personnel.

DAPATECH INTEGRATED SYSTEMS CURRENTLY INSTALLED AND TESTED

Development integrations on site
- Single-axis test rig
- Gantry robot
- Vertical milling machine
- Horizontal milling machine

Permanent integration on site
- Vertical machining centre
- Fanuc Robodrill
- 5 axis gantry mill
- 5 axis vertical machining centre

Development integration on industrial site
- Grinding machine

Permanent integration on industrial sites
- Vertical milling machines
- Horizontal machining centres
- Vertical lathes
- Five-axis milling machines

iTEC has been successfully integrated with the Fanuc Robodrill.

Ask us about our fully independent test report

BRIEF HISTORY

Various versions of the DAPATECH compensation systems have been successfully implemented with many industrial leaders including BAE systems, GKN Aerospace, Micro Metalsmiths and Rolls Royce.

However the hardware cost was a limiting factor for application in large scale. In the following two decades the research and development continued. Together with technological advancements in hardware by 2011 it became possible to consider universal integration on to new and existing machine tools. Fully developed and thoroughly tested prototypes were ready for large scale production and industrial application in late 2014.

Various versions of the **DAPATECH compensation systems have been successfully implemented** with many industrial leaders including BAE systems, GKN Aerospace, Micro Metalsmiths and Rolls Royce.

SUCCESS OF SYSTEMS

The first industrial five-axis integration was installed in 1997 and more have since been installed. Systems have proved both effective and reliable, so much so that the end-users of these systems have now many more systems and demand GTEC on all future machines used in processes requiring high and consistent accuracy.

The reported average geometric error reduction has been of the order of 8:1 and thermal error reductions of 85% can be achieved and proven by using a 180 minute heating and cooling test.

Manufactured components are more accurately produced with more consistent quality and higher production rates due to less operation intervention and inspection procedures.

Profitability is much higher with scrap rates and remanufacture immensely reduced.

The **first industrial five-axis** integration was installed in **1997** and **more have since been installed.** The reported **average** geometric **error reduction** has been of the order of **8:1 and thermal error reductions of 85%**


Visit
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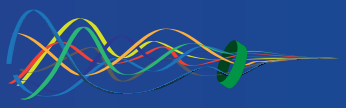
comprehensive
analysis of your
machine tool's
potential



DAPATECH SYSTEMS

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