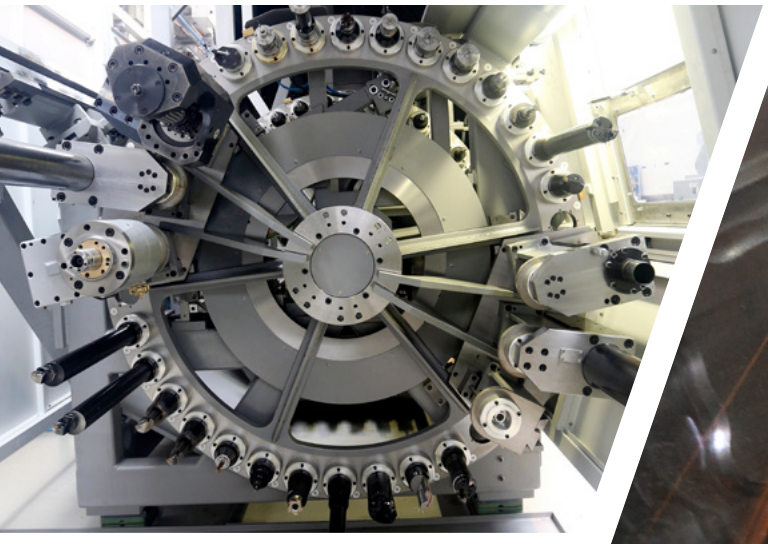
AMRC
ADVANCED MANUFACTURING RESEARCH CENTRE

The University Of Sheffield.

Machining Group

Capability directory



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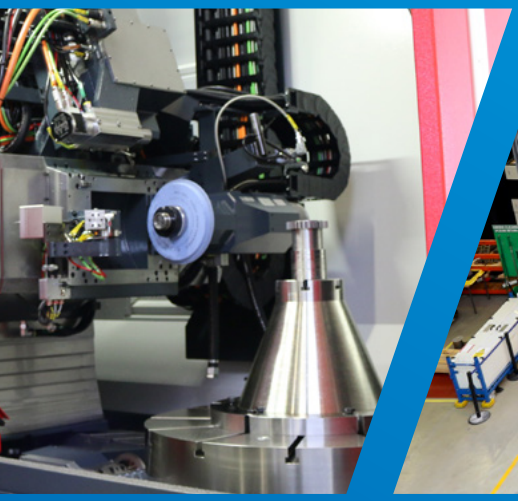
CATAPULT
High Value Manufacturing

AMRC



The AMRC Machining Group develops innovative techniques and optimised processes for the machining of high-performance materials.

The aerospace industry is driving the use of high-performance alloys and composites to improve fuel efficiency for a new generation of high-performance aircraft. Components are being produced to tighter tolerances, with more complex geometries, under increasing cost pressures. But the characteristics that make these materials attractive also make them much more difficult to cut and form.

To meet quality standards at an affordable cost, these high-performance materials require high-performance machining. The AMRC's industrial partners look to the Machining Group to apply the latest technology and innovative techniques, to produce and integrate machining solutions that deliver significant improvements in quality and cost.

We use technologies such as dynamic analysis, simulation, advanced fixturing and tool design to solve real business problems. We use a critical path approach to identify the obstacles which stop components being produced efficiently, and trade studies and cost modelling to determine the most cost-effective way to proceed.

We have a strong track record of working with the aerospace industry, and also work with companies in other high-value industries such as marine, energy, automotive, motorsports, and medical devices.

As well as process optimisation, the Machining Group develops new models of machining. The industry drive for higher tolerances is creating a demand for single-operation machining methods. We are integrating technologies and developing multi-task machining methods to significantly reduce manual intervention and downtime.

This document describes the capabilities of our technology and applications teams, and details the major machining resources of the Factory of the Future workshop.

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The AMRC Machining Group can bring a wide range of capabilities and expertise to bear on machining problems, with dedicated teams focusing on core technologies and component types.

Technology teams

Click page to jump

Our technology teams develop the techniques and underpinning science that can deliver significant improvements in machining performance, including:

See next page for: **Applications teams.**

Applications teams

Click page to jump

Our applications teams bring together experienced manufacturing engineers to focus on particular component families for our core aerospace partners. The applications teams produce demonstration components which embed the techniques developed by the technology teams into the machining process.

To put this expertise into practice, we work with an array of advanced machining centres, located in the main workshop of the AMRC Factory of the Future.

We have a wide variety of machining centres and supporting technologies, many of which are optimised for specific aerospace applications. Our resources are available for collaborative research and development projects, giving companies the capability to develop innovative and optimised machining processes without losing valuable production time on their own machines.

We count many of the world's largest and most innovative machine tool developers and tooling manufacturers among our members, giving us access to the latest models and technologies, and allowing us to push the limits of the state of the art.

See next page for: **Equipment capabilities.**

Equipment

Click page to jump

Machines by type

Mill-turn

Turning

Milling

Grinding

Hybrid

Supporting machines

Process Monitoring and Control

Process monitoring and control systems are the key to lights-out machining, where complex components can be produced without human intervention and with increased productivity and quality.

The AMRC process monitoring and control technology team aims to help UK manufacturers become more competitive by employing the latest monitoring and control tools for intelligent, autonomous manufacturing.

We focus on four essential technologies:

- Low-cost, non-intrusive sensors to obtain physical data from processes.
- Widespread connectivity of manufacturing equipment, machines and facilities.
- Robust computational intelligence for decision making from data.
- Control systems designed to react to process variations and maintain processes at optimum operating conditions.

The process monitoring and control team has a strong background in machining process development, and a wide range of experience in applying on-machine inspection probes for in-process measurement, calibration and machine health checks.

We have a range of specialised equipment tailored to the demands of our industrial partners, including:

- Process measurement systems – sensors, pre-amplifiers and data acquisition hardware including vibration and acoustic emission sensors, directional microphones, current transducers, LVDTs and non-contact displacement sensors, load cells, thermocouples and strain gauge equipment. Zigbee wireless data acquisition equipment is also available.
- Software systems – LabVIEW and MATLAB, used for data acquisition, signal processing and computational intelligence. Minitab, MODDE, and SIMCA software, for statistical data analysis, design of experiments and multivariate data analysis respectively. Software development in C++, C#, Python, and web technologies.
- Machine tool data collection – MTConnect, FOCAS, and OPC. Development of MTConnect adapters.
- Machine tool health checks – technologies for testing and calibrating machine tools, including laser interferometers, ball-bar systems and on-machine probes.

Machining Dynamics

The Machining Dynamics Group performs research and develops digital twins to predict, diagnose, and control machining vibrations and implement these technologies on industrial applications.

We focus on the following essential research strands:

Predictive models – Development of offline physics based process models and software for milling, turning, drilling, turn-milling, parallel machining, power skiving, etc. to enable feasible and stable machining parameter selection. Development of online predictive models for model based control.

Spindle dynamics – Design, development, and implementation for mechatronics systems to measure and monitor non-linear spindle behaviour. Development of analytical and numerical models to predict the non-linearity.

Workpiece dynamics – Identification of varying dynamics of workpieces during machining using experimental and simulation (FEA) based techniques.

Robotic, Robotic assisted machining – Modelling and control for robotic machining. Research on synchronised used of robots in machine tools for assisted machining.

Work-holding and Automation – Research and development of novel fixturing methodology for part dampening, distortion control, volumetric accuracy.

Vibration control – Research and development of active and passive vibration control techniques.

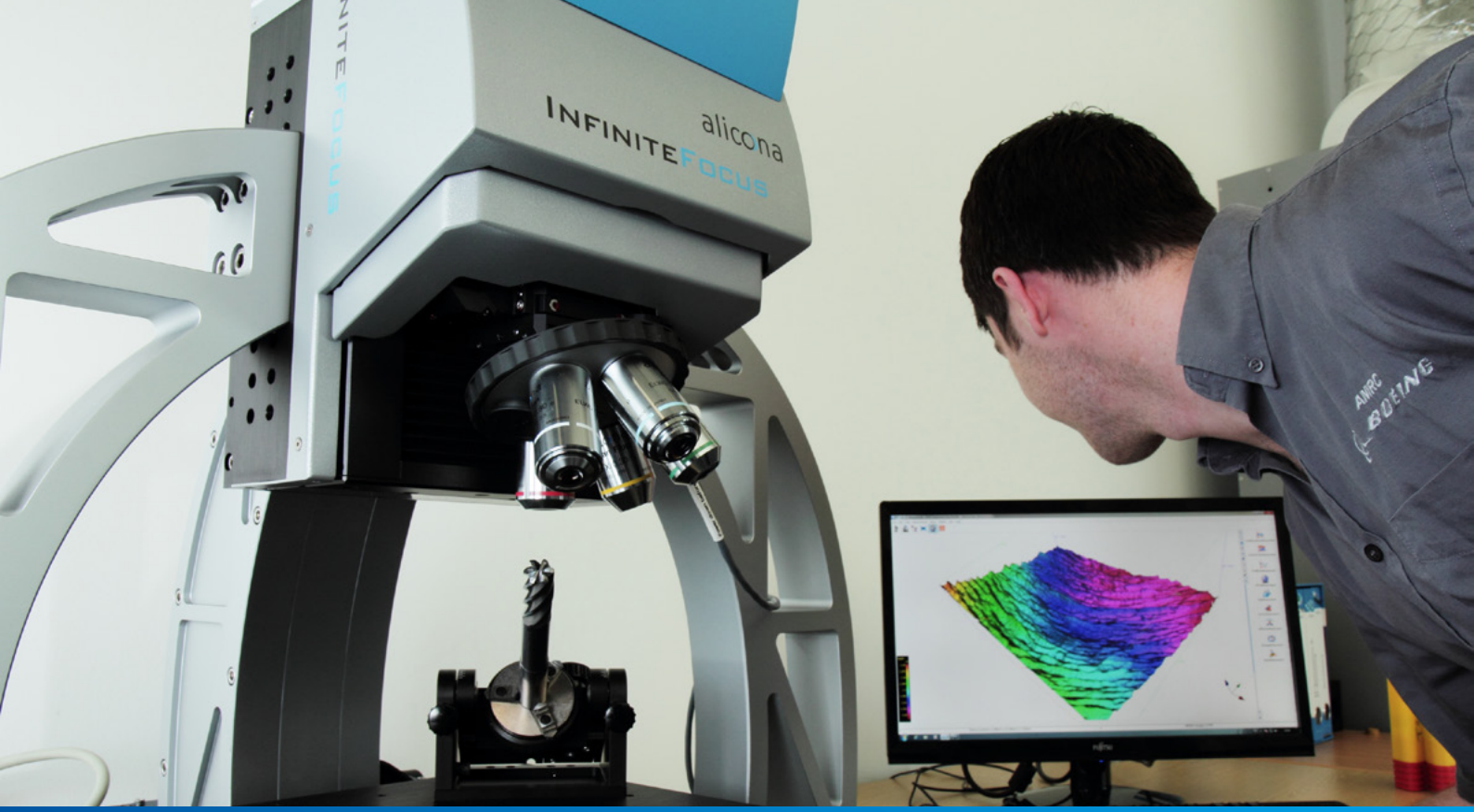
Other research strands include composite machining (in collaboration with Composite Centre) and micro machining.

We have a range of specialised equipment and software packages:

Research Platforms
- Robotic machining cell (ABB 6640 robot with 30,000rpm GMN spindle)
- Staubli robots (TX 90 & TX 200)
- Spindle test rig with a 24,000rpm IBAG spindle
- Mecos Active Magnetic Bearing based spindle/tool excitation system

Software
- Impact testing (Cutpro, Metalmax TXF)
- Process simulation & optimisation (Metalmax TXF, Cutpro, MachPro, Vericut Force)
- Data acquisition & analysis (MATLAB, Labview)
- Programming (MATLAB/Simulink, VB .Net)
- Internally developed process models

Measurement hardware
- Tap test kits
- Automated rotating spindle dynamics response measurement system (in house development)
- IBS Spindle Error Analyser.
- Force dynamometers (Kistler plate and ProMicron Spike rotating types)
- Non-contact displacement sensors (Keyence, Micro-Epsilon, Lion Precision)
- Laser vibrometer (Polytec)
- Piezoelectric strain gauges & patches



Machinability

Machinability research underpins the AMRC with Boeing's machining process work, by developing a better understanding of the essential characteristics of high-performance aerospace materials and cutting tools.

The AMRC machinability team works with a multitude of aerospace materials, focusing on titanium, high strength steel, nickel and aluminium alloys, as well as metal matrix composites.

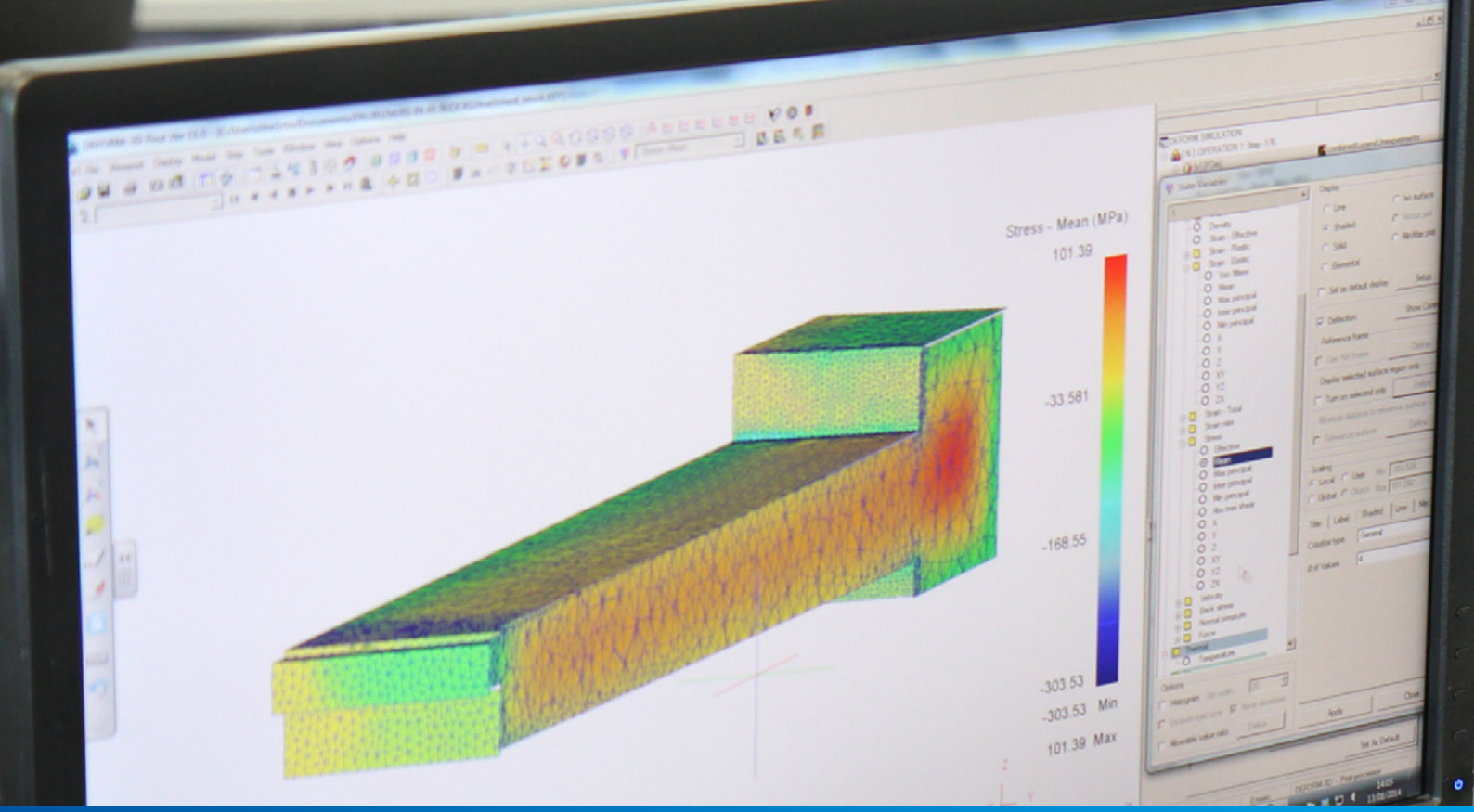
We carry out machinability research to support the work of other AMRC groups and industrial partners.

Our core research areas include:

- Characterising materials and tools
- Understanding and reducing the causes of tool wear
- Developing the chemistry and application of cutting fluids
- Understanding the material science behind machinability
- Developing emerging machining technologies

Specialist analytic equipment includes:

- **Alicona InfiniteFocus G4 & SL high-resolution 3D scanners** – used to check the geometry of cutting tools and investigate the form of finished components, with resolution of 10nm.
- **Kistler dynamometers** – to measure the cutting forces which dictate regenerative vibration limits, machine power consumption, tool deflection and tool fracture. We have three dynamometers suitable for milling and drilling studies, measuring both forces and torque, and one suitable for turning processes.
- **Carl Zeiss and USB toolmaker's microscopes** – USB microscopes are useful for rapid on-machine assessment of cutting tools. If significant wear has occurred, we can use the Zeiss microscope to carry out a quantitative flank wear assessment and track tool wear over the time of cutting.



Process Modelling

The AMRC process modelling team develops and tests techniques and computer-based models for machining processes.

We investigate metal cutting, residual stress/machining distortion, and validation of simulations through machining trials and on line /off line measurement such as residual stress, cutting forces, temperature, distortions.

We use computer-based models to investigate alternative machining processes, helping companies make more informed decisions. These models reduce the need for costly shop-floor trials, and shorten the lead time in bringing a new product to market.

We aim to cover all areas of modelling relevant to our industrial partners.

Core capabilities include:

- Prediction of residual stress; machining distortion and feedback loop for tool path optimisation. We can integrate process models and in-process monitoring to investigate and validate the models to develop optimised machining strategies based on part distortions. Chip formation analysis in metal cutting modelling to better understand the relationship between the many process parameters and the machining responses as well as surface integrity. By modelling material removal, we can reduce the cost of experimental tests optimise cutting conditions, and redesign tool geometry. We also have capability for simulation alongside experimental work for Ultrasonic assisted machining assisting for example in force reduction in difficult to cut materials.
- We have extensive software resources, including tools for finite element analysis, optimisation analysis, design of experiments and programming. Software providers and packages include, Deform, Abaqus, Ansys, Matlab, Simufact, Umetrics and others.

We also have access to the Iceberg high-performance computing cluster at the University of Sheffield.

Residual Stress Measurement

Understanding the development and distribution of residuals stresses (RS) during manufacturing is a key factor in the development of methods to minimise distortions in components during machining.

Research

The Residual Stress Measurement Group at the AMRC has interest in investigating the factors that influence the generation and distribution of residual stresses (RS) in manufacturing processes, including:

- Development of an understanding of the factors that influence the generation and distribution of RS during heat treatment
- Effect of process variability on RS
- Machining-induced stresses
- Influence of RS on machining distortions
- Interaction of near and bulk RS
- Validation of process models in-house for RS predictions

Capabilities

- **Portable X-ray Diffraction System (XRD)**
  X-ray diffraction can be used to measure residual stress using the distance between crystallographic planes, i.e., d-spacing, as a strain gage.
- **Ultrasonic Stress Measurement System**
  The portable, semi-automatic device for Ultrasonic Measurements of Applied and Residual Stress is designed for measurement of bulk and surface residual and applied stresses in samples, parts, welded elements and structures non-destructively.
- **Contour Measurement Technique**
  Contour measurements are used to measure bulk residual stresses. Contour measurement is performed as following: 1) EDM machine; 2) CMM machine and 3) FE Modelling.

Grinding

Grinding and surface finishing operations can account for 20-25 per cent of expenditure on all machining operations. Many components are primarily machined using these techniques, while others rely on such processes for final accuracy and precision.

The AMRCs machining group has developed a Grinding Centre of Excellence to support the demand identified by UK industrial partners for capability in grinding technology. The focus has been on the development of a broad spectrum of technologies spanning TRL levels with a view to bridge research and technology demands through to applied requirements.

Our machine tool capabilities and research framework span a range of grinding processes, core research themes, sectors and commodities.

Machine tool capabilities span a range of grinding processes:

- Cylindrical grinding
- Surface and profile grinding
- Gear grinding
- Multi-functional grinding
- Ultrasonic grinding

Core topics:

- Grindability of materials
- Process monitoring and control
- Method of manufacture development
- Process optimisation
- Advanced materials
- Hybrid grinding processes
- Flexible grinding processes

Key machining resources include:

- Studer S41
- Makino G7
- Blohm Profimat MC607
- Blohm Prokos XT
- Höfler Rapid 1250XLK
- DMG Mori NT4250
- haas Multigrind CB
- DMG Mori US10

Hole Generation

In aerospace manufacturing, virtually every engineered component features some form of hole. For airframe manufacturers such as Airbus and Boeing the sheer volume of holes that are required to be produced is in excess of a million holes every day. These holes have to be created to high tolerances for components that are often containing multiple dissimilar material combinations. For example, titanium, aluminium and carbon fibre reinforced plastic (CFRP) stacks.

During the manufacturing process every hole has to be precisely positioned and machined, by either drilling, milling or via eroding strategies. Hole generation for such components carries high risk, with any errors potentially resulting in finished components being scrapped.

The AMRC hole generation team is dedicated to improving the performance and quality of hole generation techniques.

We aim to cover all areas of hole generation relevant to our industrial partners.

Our current research areas include:

- Development of tool technologies including geometry, materials and coatings
- Tooling design and machining strategy optimisation for robotic systems
- Development of low torque machining practices such as orbital drilling
- Establishing one-way assembly manufacturing strategies for multiple-stack componentry
- Implementation of clean machining strategies which either reduce or eliminate the use of oil/ fluid coolants
- Integration of automatic and robotic manufacturing methods for increased rate of manufacture
- Topographical and subsurface metallurgical analysis of machined components with respect to their in service properties
- Development of One-shot manufacturing strategies.

Cutting Tool Technology

The Cutting Technology research group focus on the transition of new research innovation to application, through the manufacture industrial representative feature based demonstrators. By taking a bench-marking approach, trends in technology progression and the potential for an emerging technology to influence manufacturing cost and productivity can be quantified.

The team itself comprises experienced application engineers and engineers with an academic interest, providing a unique insight into the challenges of both.

The team's research focuses on:

- Feature-based cutting strategy development: The application of metal cutting principles and simulation tools to aid milling, drilling and turning strategy development.
- Cutting tool assessment & parameter optimisation: Applying statistical methods driven by process cost or productivity drivers, typically cutting strategy driven.
- CAM assessment, driving strategy uptake: Utilisation of both industry leading and internally developed simulation and measurement systems to assess and refine CAM and machining performance.
- Automation of testing processes and standardisation of cutting tests.

Equipment portfolio:

- Refurbished MAG Cincinnati H5-800, having comprehensive process and equipment monitoring systems. A high torque, horizontal platform idea for aggressive milling trials.
- DMG DMU 40 eVo, 18k RPM 5 axis platform, ideal for strategy development where higher RPM's are required and for intricate and high accuracy 5-axis machining, such as aerofoil demonstrations.
- Pro-micron spike® systems (strain gauge based bending and torque measurement) facilitating force measurement for complex component manufacture where traditional dynamometry is not feasible.

Emerging Technologies

The Emerging Machining Technologies research group performs research in developing and proving out novel machining technologies that can be applied in industrial environments. The focus of the team is to investigate the feasibility of technologies that have the potential to provide a step change over existing processes in terms of performance and quality.

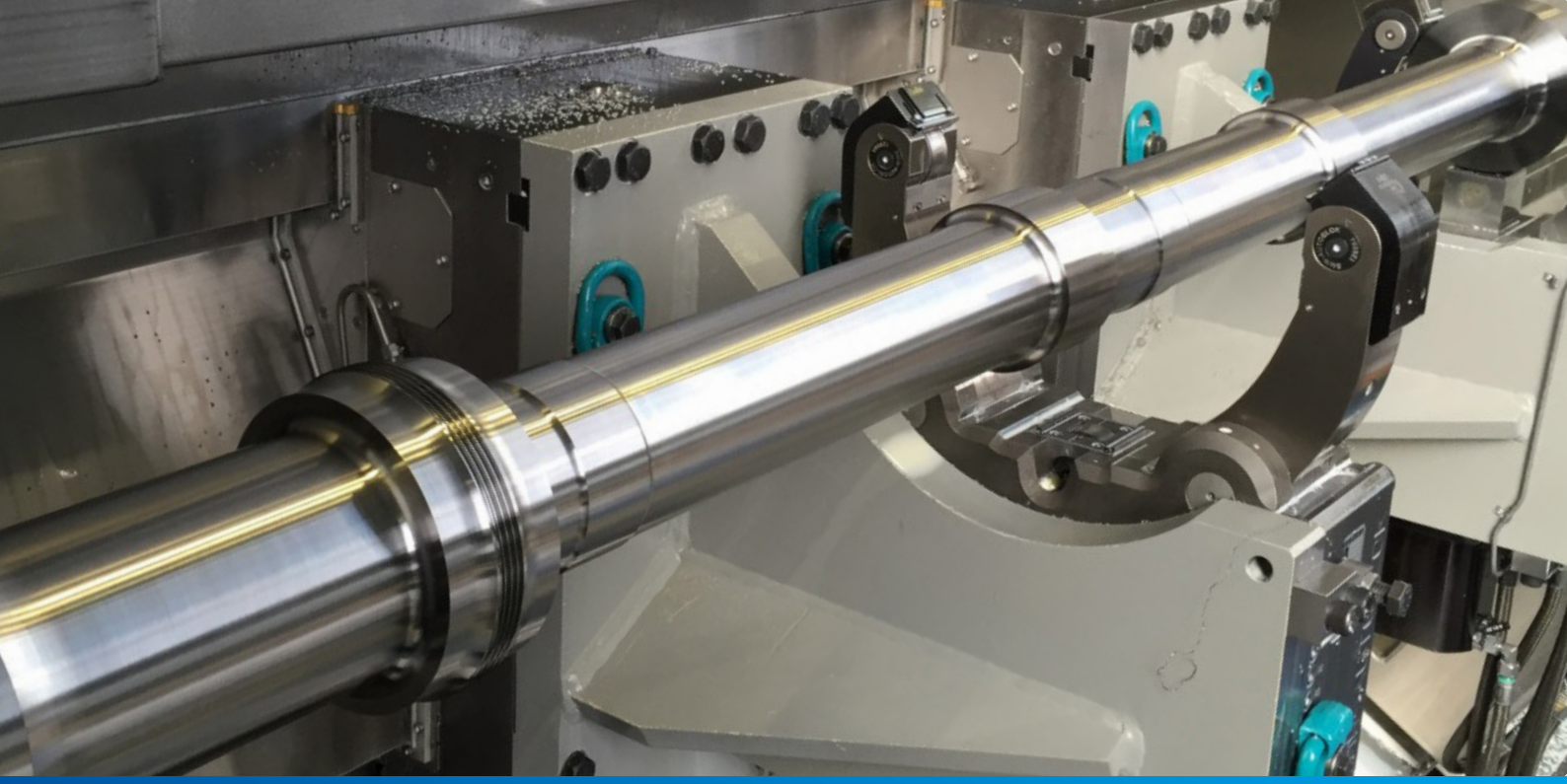
The Emerging Machining Technologies team at the AMRC has an interest in investigating new machining technologies that have the potential when scaled up to provide considerable benefits in existing machining processes.

Research Strands:

- **Hybrid (additive and subtractive) machining:** The combination of additive and subtractive machining under one platform opens up new opportunities in terms of creating complex geometries with multiple materials.
- **Cryogenic machining:** The use of cryogenic cooling liquids has shown the potential to improve tool life and part quality in machining operations whilst eliminating the need for emulsion coolants.
- **Ultrasonic machining:** The machinability of aerospace materials has the potential to be improved by using t vibrations in the ultrasonic range. This allows improved chip management as well as improved final part quality.
- **Laser assisted machining:** In hard to machine alloys, the use of lasers for local softening of the material can improve the machinability, reduce the cutting forces and tool wear while machining.

Key resources include:

- DMG Lasertec 65 3D Ultrasonic machining centre
- Starrag LX 051 cryogenic machining centre
- Fusion Coolant system supercritical CO2 cryogenic machining setup
- Photron Fastcam UX100 High speed camera.



Rotatives

The AMRC rotatives team focuses on techniques and tools for machining discs, rings and shafts mainly for the aerospace industry.

These components play a significant role in the efficiency of gas turbines, and can present major challenges for machining and inspection. With over a decade's experience of solving manufacturing challenges across a range of aerospace components, the rotatives team aims to develop high-performance manufacturing strategies for new disc, ring and shaft components.

The team has a track record of delivering solutions to industry partners in terms of development of world-class methods of manufacture for high precision new products, and improvement of existing methods – Right-First-Time rate increase, cycle time and number of operations reduction – all the way through to implementation into our partners' facilities with on-site support.

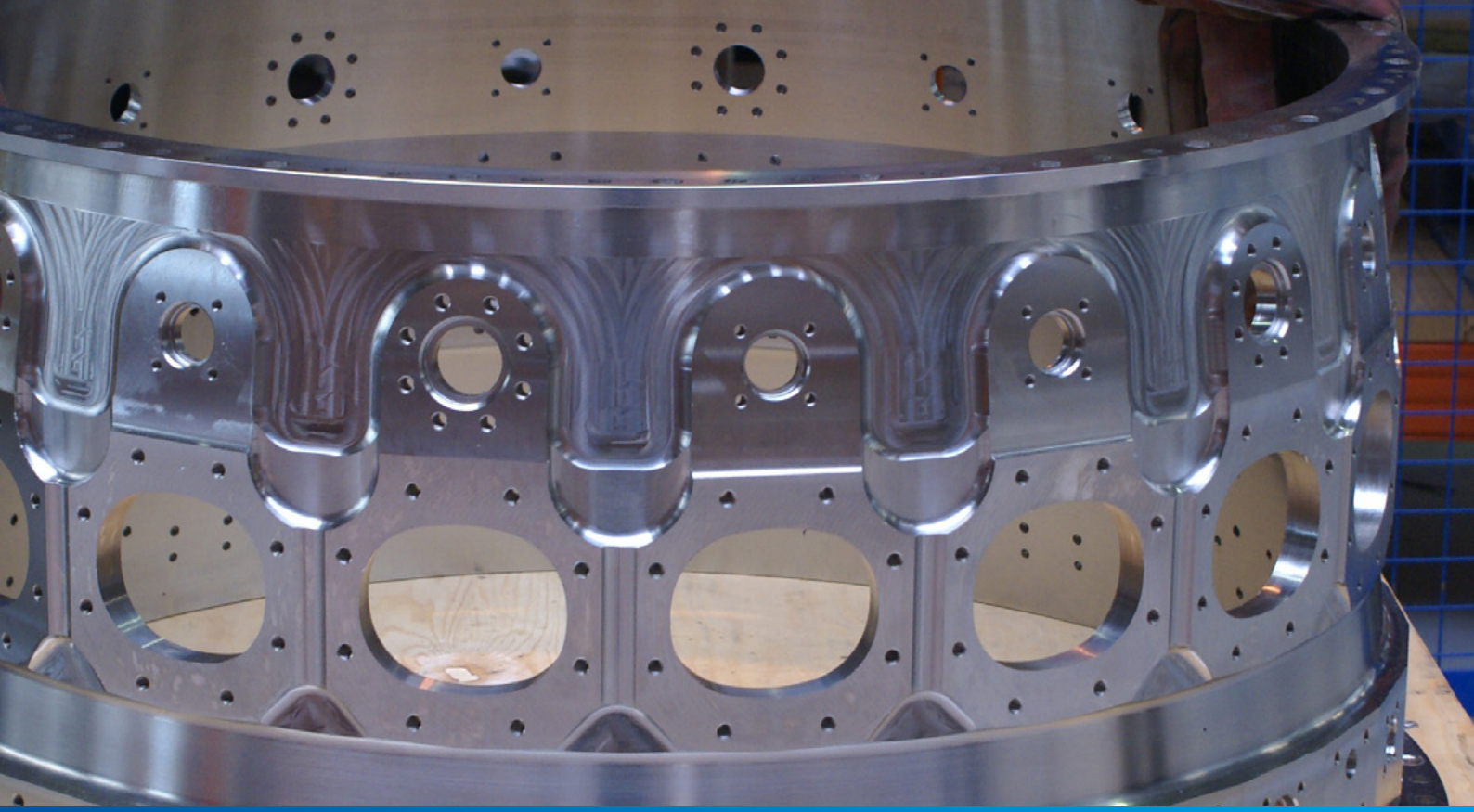
Key machining resources include:

- WFL M100 turning-boring-milling centre
- DMG Mori NMV8000 five-axis mill-turn-grind machine
- DMG Mori NT5400 five-axis mill-turn
- Hermle C52 five-axis mill-turn
- WFL M30 turning-boring-milling centre

Key areas of current research include:

- New Method of Manufacture development
- Distortion compensation
- Fixturing design
- Feature-specific tooling
- Tool path strategies
- Measurement strategies
- New materials
- Swarf control
- Novel tooling applications

We also lead specific research on critical features to increase metal removal rate, develop processes for new alloys, and create tooling solutions for complex part geometries.



Casings

Aeroengine casings have complex geometries and are made from expensive, difficult-to-machine alloys demanded by their increasingly tough operating conditions. Reducing their machining cost while maintaining quality is a critical challenge for many of the AMRC's partners.

The AMRC casings team has researched casing machining since 2005. From our first studies on metal removal rates and vibrational assessment of current industry methods, we have developed a range of novel strategies, tooling and workholding technologies to optimise casing machining.

We have worked with a leading aeroengine partner to combine many of these techniques into a state-of-the-art machining strategy for specific casings which are now in production.

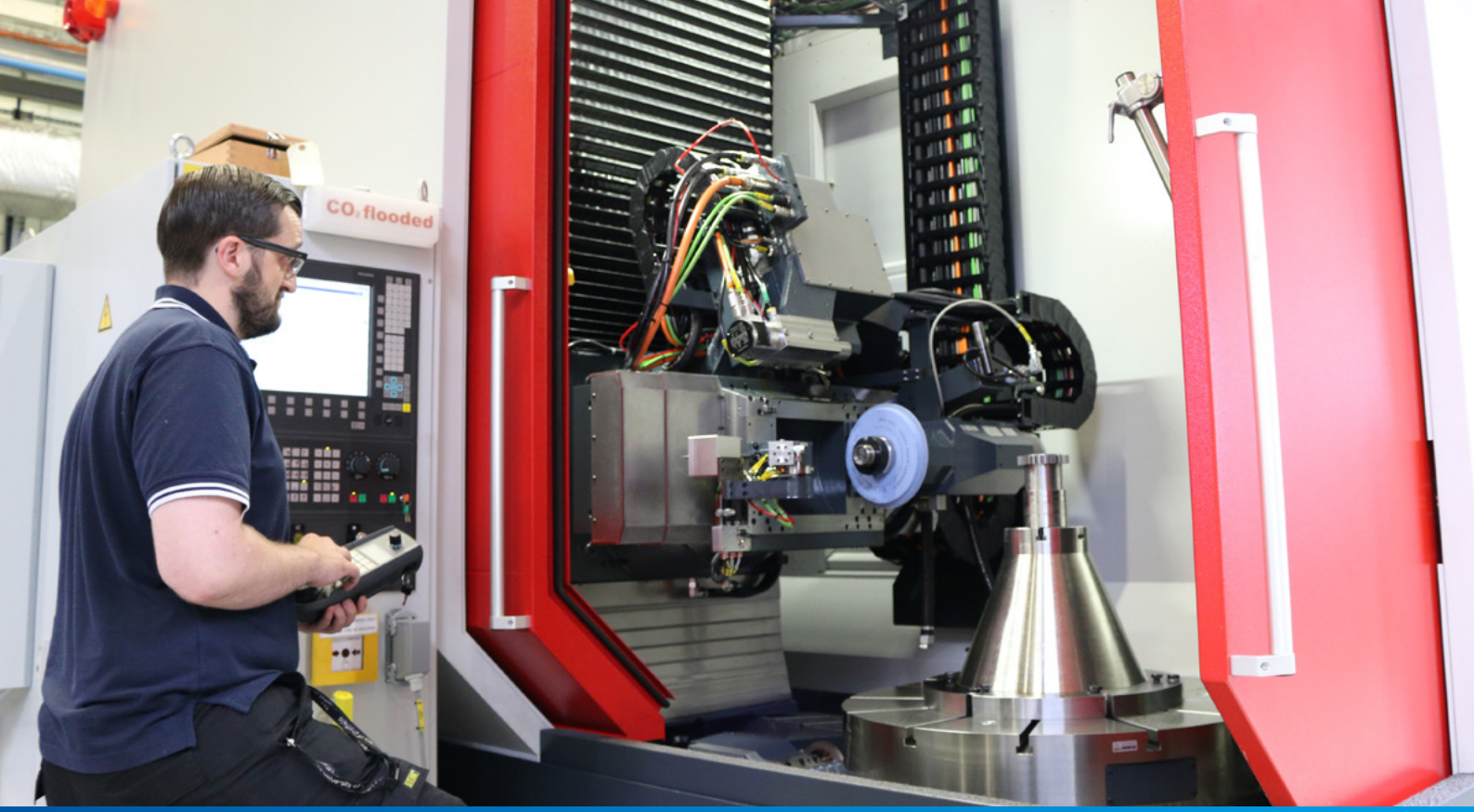
We develop the technology and application processes to create world-class machining solutions for whole casing component development or single feature optimisation.

We are currently working in areas such as:

- Metal removal rate improvements and cycle time reductions
- Working with production engineers to seamlessly transfer research into the manufacturing environment
- Machining vibration & stability optimisation through work-holding, tooling and CAM strategies
- Optimising tool usage and feature-specific tooling
- Driving machining strategies to go 'green-button' while maximising productivity and process robustness

Key machining resources include:

- Hermle C52



Gears

The AMRC's Gear Engineering and Research (GEAR) Centre is a new group within AMRC Machining, started in January 2015. We are bringing AMRC's fundamental research model to a new platform and new industries.

Whilst belonging to the Machining Group, we aim to be a centre-point for collaborative projects on gear and transmission research. Our initial focus is on flexible and novel machining methods as well as surface finishing, treatment and characterisation for gears, splines and transmission components.

AMRC GEAR Centre core process competencies:

- Gear machining on multifunctional machines
- Done-in-one gear manufacture
- Generative gear milling
- Form gear milling
- Single point broaching
- Power skiving
- Multi-functional grinding
- Multi-functional inspection

AMRC aspirations for future state of gear manufacture:

- Utilising multifunctional machines in a single setup for efficient gear production
- Flexibility in manufacturing process for a range of volumes
- Design freedom with flexible manufacturing methods
- Configurable manufacturing processes for operation roll-up and added value
- Gear performance evolving rapidly to embrace opportunities offered by new manufacturing and material technologies
- UK sector bolstered through innovation

Aerofoils

Aerofoils are some of the most critical aeroengine components. Their material capability and geometry directly affect engine performance and fuel consumption.

The aerospace industry's constant drive to improve performance and efficiency places increasing demands on aerofoil manufacturing processes. These improvements must be achieved through cost-efficient manufacturing processes which can meet production targets.

The AMRC's aerofoils platform team, is dedicated to improving the performance and quality of aerofoil and blisk machining utilising novel tooling and machining strategies, advanced work holding and on-machine alignment techniques. We are experts in the application of dynamic analysis to optimise machining operations for complex aerofoil components.

Our current research areas include:

- Advanced materials and condition of supply
- Advanced component design and tighter tolerance features
- Cost-based method of manufacture development
- Process control, monitoring and modelling
- Green button manufacturing methods
- Adaptive manufacturing methods
- Measurement technology for aerofoils
- Milling, grinding and surface finishing processes

Core machining resources include:

- Starrag LX-051 aerofoil machining centre
- Starrag NB251 blisk and impeller machining centre
- DMG Mori NT5400 five-axis mill-turn
- DMG Mori NT4250 mill-turn-grind automated cell
- Starrag-Heckert STC1250 horizontal machining centre
- DMG Mori NMV8000 five-axis mill-turn-grind machine
- Hermle C52 five-axis mill-turn
- Rosler vibratory bowl
- Rosler drag finisher

Structures

Structural parts for aerospace present major manufacturing challenges, thanks to the complex nature of their geometries.

Aerostructures and landing gear components play a crucial role in all aircraft. Given the role that these components play on an aircraft, they are made from some of the most advanced materials available on the market today; from nickel alloys and titanium to high grade aluminium. To ensure the production of these materials remains efficient and cost effective on a continued basis, the continued development of skillful manufacturing processes is required.

To ensure our partners achieve the desired efficiency and robustness, along with aiding in the development of new and novel processes, the team employs best practice process methodology and tooling selection that is refined on a regular basis. We build and manipulate complex cutter paths and unique work holding solutions to demonstrate improved manufacturing processes and develop them to production readiness in line with partner deadlines and requirements.

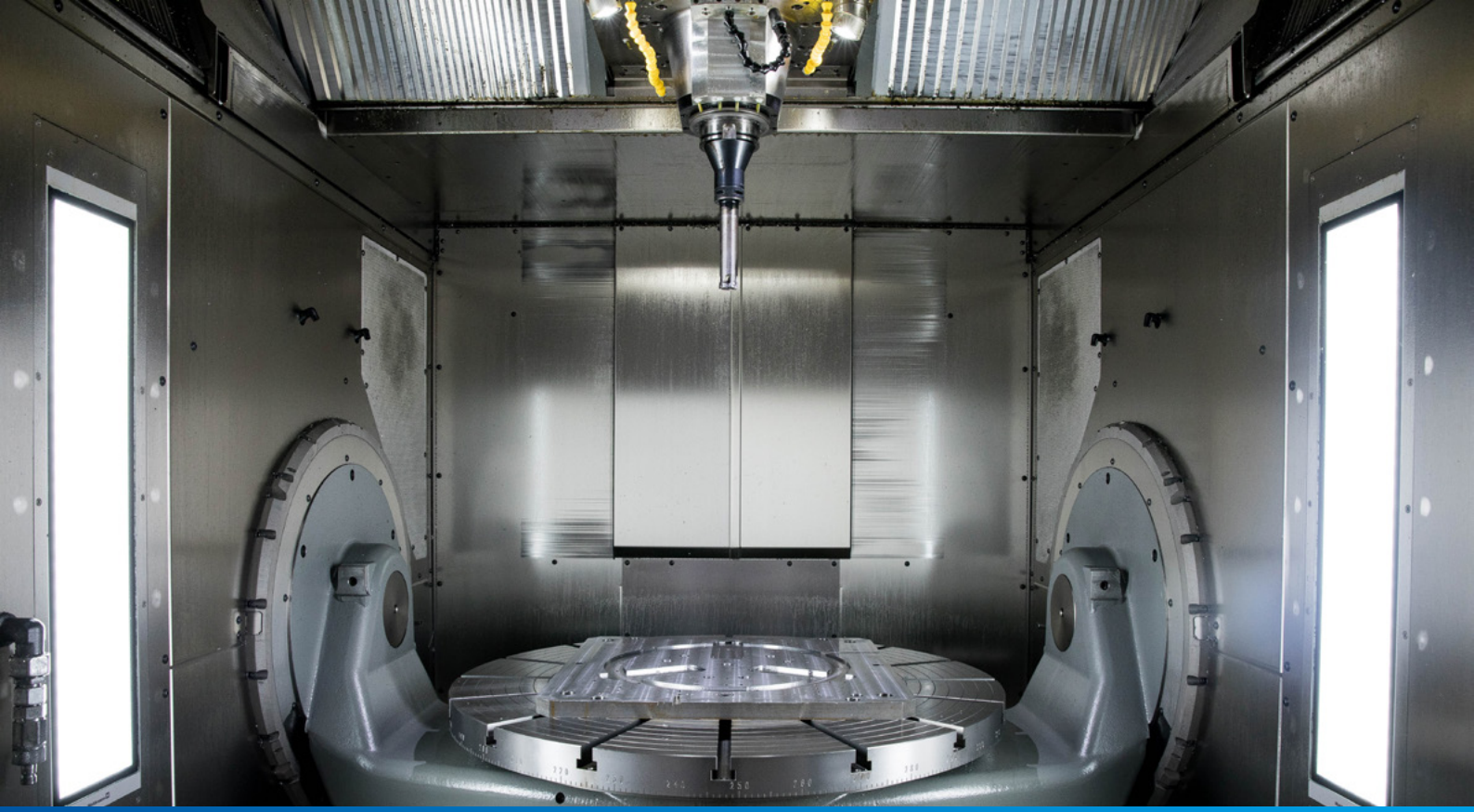
Key research areas include but are not limited to:

- New and novel manufacturing solutions surrounding structural and landing gear components
- The development of damped and rigid work holding for mill turn platforms
- Complete process review of large aluminium rib components with the intent of providing a step change in part manufacture
- Method of manufacture development for actuation components

Key Resources:

- Scharmann Ecospeed high-speed five-axis machine
- Starrag STC 1250 horizontal machining centre

Along with the above, the team has access to a world-leading selection of mill-turn machining centres within the AMRC Factory of the Future along with a range of other machine tool configurations, including those available at the NAMRC, such as the Soraluce FX12000. Access to this equipment has allowed us to demonstrate optimised manufacturing on alternative and non-standard machining platforms.

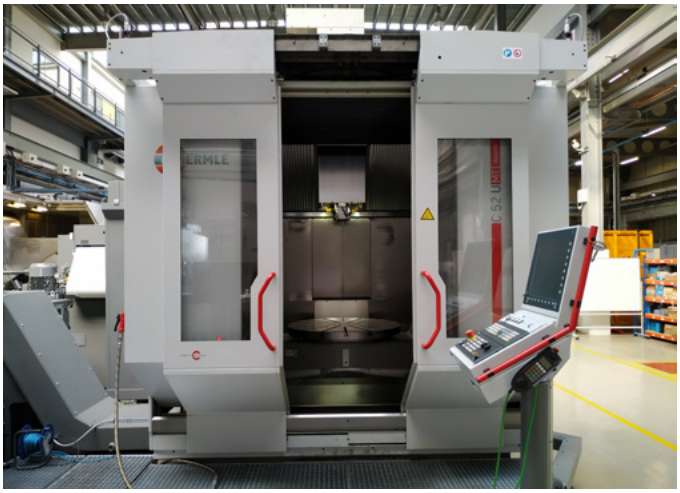


Hermle C52

Highly flexible five-axis machining centre, capable of a range of cutting operations to high precision.

A highly flexible five-axis mill-turn centre, the C52 is capable of a range of cutting operations to high precision, including blisk, bling and impeller applications.

The C52 can handle workpieces up to 2000kg, and is ideal for difficult-to-machine materials.



Type	5-axis vertical mill turn
X-axis travel	1,000mm
Y-axis travel	1,100mm
Z-axis travel	750mm
Max spindle speed	12,000rpm for milling spindle
Max spindle torque	356Nm
Max spindle power	56kW
Spindle interface	HSKA/T 100
Coolant delivery type	HPC through spindle
Max acceleration, linear axis	6m/s^2
Max acceleration, rotary axis	6m/s^2
Max workpiece size	800mm x 800mm x 500mm
Max workpiece weight	2000kg
Additional functionality	Turning capability

Doosan Puma Lathe TT1800SY

Twin spindle twin turret production lathe for high-productivity machining of small cylindrical components. Includes bar feeder, quick-change collet and mandrel system, and parts catcher for continuous production with minimised manual intervention. Features turret milling for prismatic features and drive of live tooling.

Max turning diameter:	230mm
Max workpiece length:	200mm
Bar feed maximum diameter:	65mm
Max spindle speed:	5000rpm
Max spindle power:	22kW
Turret interface:	BMT50

DMG Mori NMV8000 DCG

Five-axis milling, turning and grinding machine, equipped with Renishaw scanning probe technology.

Five-axis mill-turn-grind capability for larger diameter components. The NMV8000 allows the development of multi-task machining processes for a variety of component families.

It is one of the most accurate and dynamically stable machine tools at the AMRC, offering an ideal platform for both rotating and prismatic part machining.

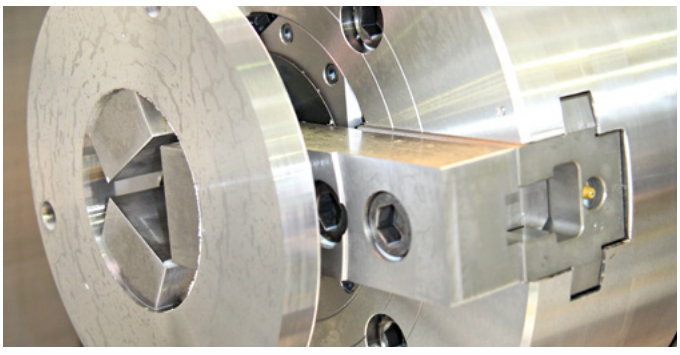
Type	5-axis milling with grinding capability
X-axis travel	1,200mm
Y-axis travel	920m
Z-axis travel	610mm
B-axis travel	+160° to - 180°
C-axis travel	360°
Max spindle speed	10,000rpm
Spindle interface	BT50
Max workpiece size	Ø1,000mm x 500mm
Max workpiece weight	1000kg

DMG Mori NT5400 DCG

Five-axis milling and turning machine, equipped with Renishaw scanning probe technology.

Five-axis milling and turning machine, equipped with the latest on-machine scanning probe technology from Renishaw. The NT5400 has twin chuck capability for green button manufacture, and is capable of parallel turning using a second turret system.

For aerofoils, the NT5400 offers flexible five-axis mill-turn capability for single blade machining, from a range of inputs including forging and bar stock. Twin spindle and lower turret application allow the development of single-hit machining for complex aerofoil geometries.



Type	5-axis horizontal mill-turn-grind
Max spindle speed	Lathe spindles: 2,400rpm Mill spindle: 6,000rpm
Max spindle torque	Lathe spindles: 1,432Nm Mill spindle: 30Nm
Max spindle power	Mill spindle: 30Nm Lathe spindles: 37kW Mill spindle: 5.5kW
Spindle interface	Capto C8
Coolant delivery type:	HPC through tool
Max workpiece size	920mm swing, 1,921mm max length
Additional functionality	SQUAD laser scanning. Spin turning. Involute milling. Pinch/parallel milling capability. Process monitoring system.

DMG Mori NT4250 DCG

Five-axis mill-turn-grind centre.

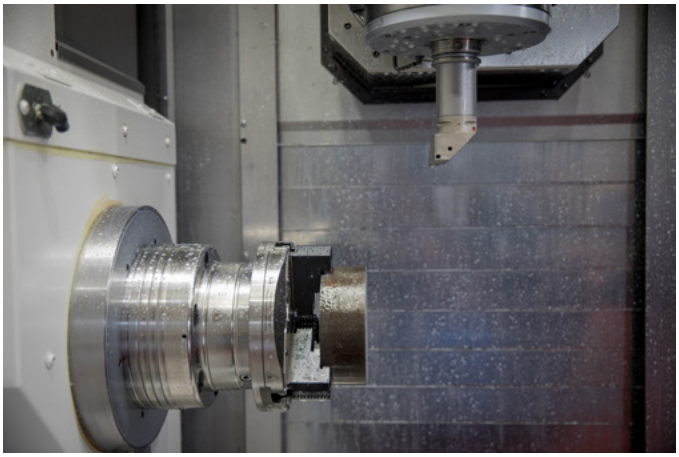
Flexible five-axis mill-turn-grind capability for component manufacture from a range of input conditions. The NT4250 is capable of handling a wide range of component handling, component transfer, wheel dressing and coolant applications.

Description	5-axis turn-mill platform with grinding capability.
Capacity	1542 x Φ660 mm.
Wheel heads / spindle	**Wheel spindles** 220x30 mm form 1 (32 mm bore), 18.5 kW, 12000 rpm. **Dresser spindle** 5.5 kW, 6000 rpm.
Coolant	Emulsion (70 bar, 100 l/min [cleaning and cooling]).
Functionality	Dressing via lower turret spindle. Programmable coolant delivery via 3-axis lower turret method.

Okuma Multus U3000

Horizontal mill-turn featuring high precision rotary encoders for exceptional timing and positioning accuracy to suit gear cutting processes including power skiving. Featuring twin turning spindles with automated part transfer capability, as well as upper spindle and lower turret for simultaneous milling and/or turning operations.

Maximum workpiece size	ø650 x 1600 mm
Spindle interface	660mm diameter, 721mm length
Turning spindle speed	5000 rpm
Milling spindle speed	10,000 rpm
Milling spindle torque	120 Nm
Milling spindle power	22 kW



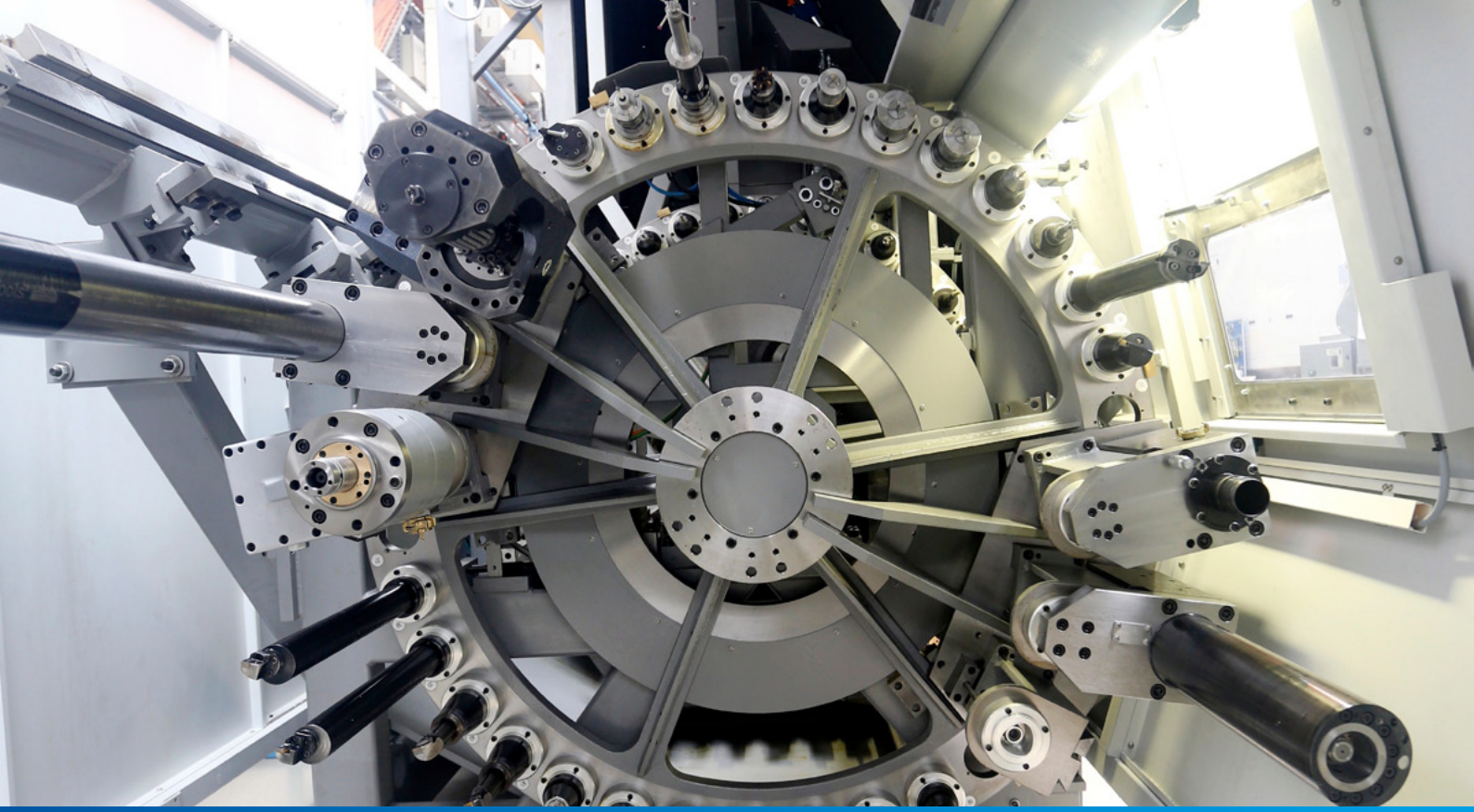
WFL M30-G

Horizontal mill-turn with capability for heavy duty applications such as forgings and hard materials. Including twin turning spindles with automated part transfer capability, as well as upper spindle and lower turret for simultaneous milling and/or turning operations.

Five-axis milling and turning machine, equipped with the latest on-machine scanning probe technology from Renishaw. The NT5400 has twin chuck capability for green button manufacture, and is capable of parallel turning using a second turret system.

For aerofoils, the NT5400 offers flexible five-axis mill-turn capability for single blade machining, from a range of inputs including forging and bar stock. Twin spindle and lower turret application allow the development of single-hit machining for complex aerofoil geometries.

Type	5-axis horizontal mill-turn with twin spindles and driven lower turret
Milling spindle speed:	9000 rpm
Milling spindle torque:	165 Nm
Milling spindle power:	20 kW
Turning spindle(s) speed:	4000 rpm
Max turning spindle(s) torque:	630 Nm
Max turning spindle(s) power:	33 kW
Spindle interface	HSK63
Coolant delivery type:	HPC through tool
Max workpiece size	⌀520 x 1800 mm
Additional functionality	Lower turret turning and milling, gear hobbing, shaping, power skiving and reciprocating single-point broaching.



WFL M100

Large turning-boring-milling centre, capable of machining complex geometries to the highest precision.

Large turning-boring-milling centre, capable of machining complex geometries to the highest precision. The M100 is ideal for working with difficult-to-machine materials, high-volume material removal, and deep ID-machining.

It features a turning length of over five metres, turning spindle speed of 1600rpm and milling spindle speed of 6000rpm.

Type	Turn-bore-mill
X-axis travel	900mm
Z-axis travel	5,700mm
Max spindle speed	Turning: 1,600rpm Milling: 6,000rpm
Max spindle torque	Turning: 5,290Nm Milling: 315Nm
Max spindle power	Turning: 71kW Milling: 30kW
Max workpiece size	Turning length: 5,200mm Centre distance: 500mm

DMG Mori NLX2500 | 700 and Robo2Go arm

A modern NC lathe with automation capability, used as an experimental machinability platform.

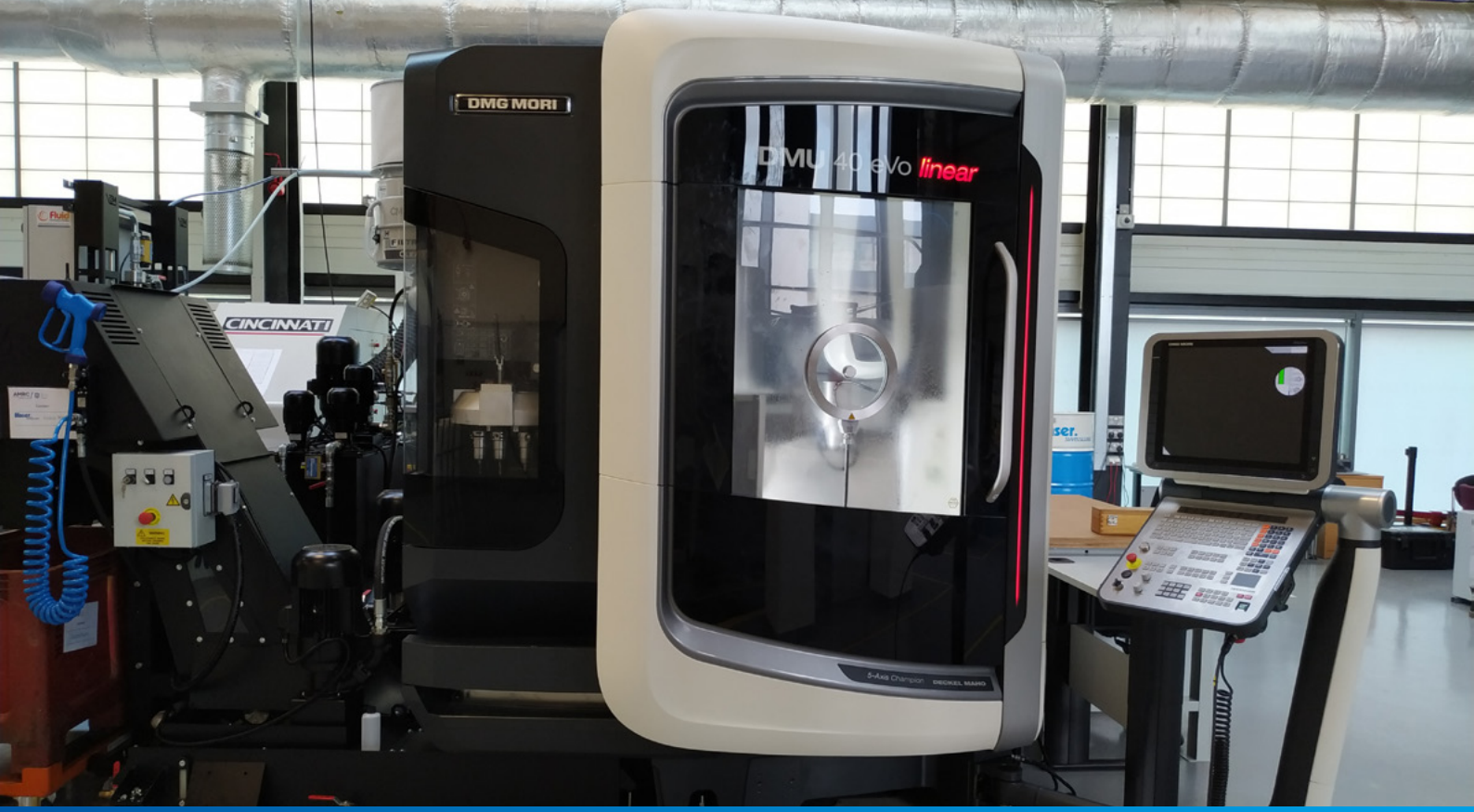
The NLX 2500 | 700 is a high-rigidity, high-precision turning centre. The model flexibly handles various workpieces with a highly rigid bed and powerful turning capability. Equipped with CELOS and MAPPS V, the NLX2500 enables operators to perform machining of various workpieces from simple to complex shaped components with an easy operation. Robo2Go is a mobile automation system for lathes that is designed for easy programming using a smartphone app. Robo2Go includes a six-axis robot with up to 35kg load, and features barrier-free safety technology, and is programmed via a special CELOS app with just a few entries.

DMG Mori NLX2500 | 700

Standard turning diameter	268 mm
Max. turning diameter	460 mm
Max. chuck size	254 mm
Max spindle speed	4,000 rpm
Drive power rating (100% DC)	22 kW (AC)
Max turning length	728 mm
Bar work capacity	90 mm

Turret type	10 station type
Coolant	70 bar
Spindle 1 drive motor	18.5/18.5/15 kW

Robo2Go Fanuc robot arm integrated



DMG Mori DMU 40eVo

Combines the flexibility of high-tech universal milling machines and the performance potential of vertical machining centres.

In doing so, the innovative machine concept with an optimised gantry, the optional linear drive in the X and Y-axis and the proven swivelling rotary table provide maximum productivity and flexibility. The NC swivelling rotary table with a large swiveling range of -5° to +110° enables 5-axis simultaneous machining for best surface qualities and extends the options of this machine in all manufacturing areas – both in complete processing of individual parts and in series production.

Type	5 axis vertical milling machine
X-axis travel	400 mm
Y-axis travel	400 mm
Z-axis travel	375 mm
B-axis travel	-5° to 110°
C-axis travel	360°
Max table load	250 kg
Table size	450 x 400 mm
Max spindle speed	18,000 rpm
Max spindle power	26 kW
Max spindle torque	709 Nm

DMG Mori Ultrasonic 10

5-axis ultrasonic grinding platform.

The DMG Mori Ultrasonic 10 is an ultrasonic machining platform capable of mill-drill-grinding process on small compact component geometries. High spindle speed capability enables small tooling for intricate machining.

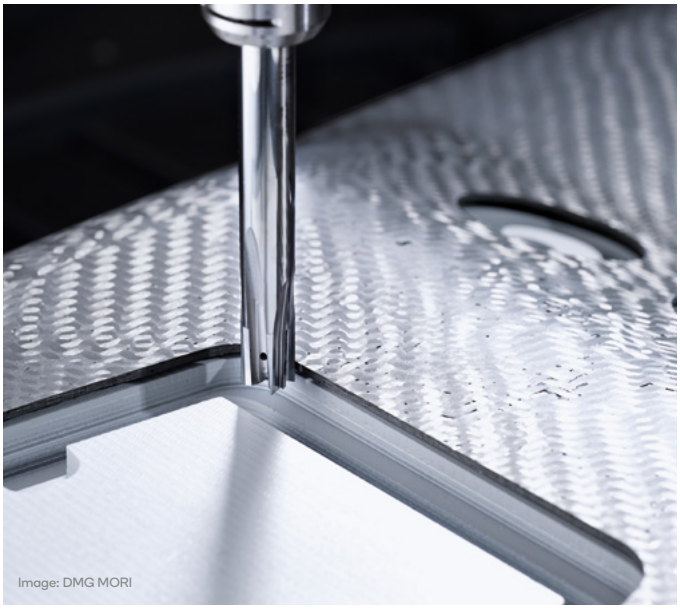


Image: DMG MORI

Description	5-axis ultrasonic machining centre (mill-drill-grind)
Capacity	Ø190 x 200 mm 10 kg maximum weight
Wheel heads / spindle	**Wheel spindles** HSK32 interface – 7.7kW, 40,000 rpm with axial ultrasonic assistance
Coolant	Emulsion coolant only, supplied at 30 bar through spindle
Functionality	GEN1 ultrasonics

DMG Mori NVX5080

A modern 3-axis NC milling machine used as an experimental machinability platform.

The NVX NC milling machine is used for stripped-down, simple and repeatable testing of the latest cutting fluids, milling and drilling tools and aerospace alloys. It has a rigid 3-axis spindle with a relatively high maximum speed. The machine is customised with IFDR (Intelligent Fluid Delivery & Recycling) cutting fluid delivery and filtration.

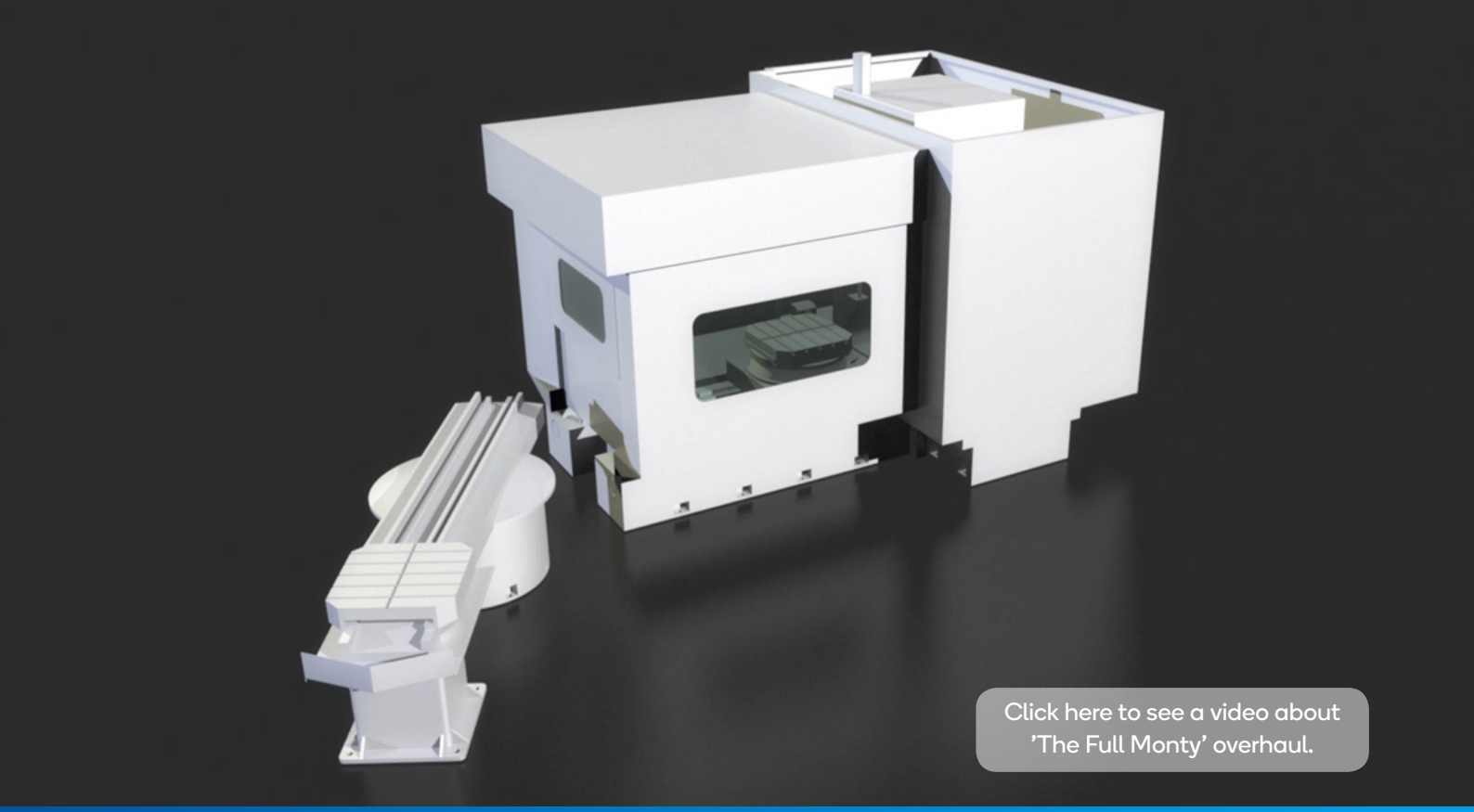
Type	Vertical Milling Machine
X-axis travel	800mm
Y-axis travel	530mm
Z-axis travel	510mm
Max spindle speed	15,000rpm
Max spindle power	30kW
Max spindle torque	207Nm
Table loading capacity	1000kg

KERN Evo

The KERN EVO is an ultra precision machining centre with the highest level of accuracy in standard 3 axis configuration.

The working envelope is 300 x 280 x 250 mm. The machine bed is manufactured from a thermally stable and vibration dampening polymer concrete material as a single mono-block unit.

Type	3 axis vertical machining centre
X-axis travel	300mm
Y-axis travel	280mm
Z-axis travel	250 mm
B-axis	-10° to +100° (pivoting)
C-axis	360° endless
Max speed	50,000
Full load torque max (S1)	1.43 Nm
Full load torque max (S2)	1.86 Nm
Power max	6 kW



MAG Cincinnati H5-800

Flexible five-axis horizontal machining centre for multi-function and high-efficiency processing. High specification sensing and data acquisition capability.

The H5-800 integrates five-sided processing and five-axis contouring into a single agile platform.

The machine features a 180° A-axis tilt spindle sweep at 60° above horizontal and 120° below horizontal. The table is capable of continuous rotation. All axes work together to provide full five-axis capability.

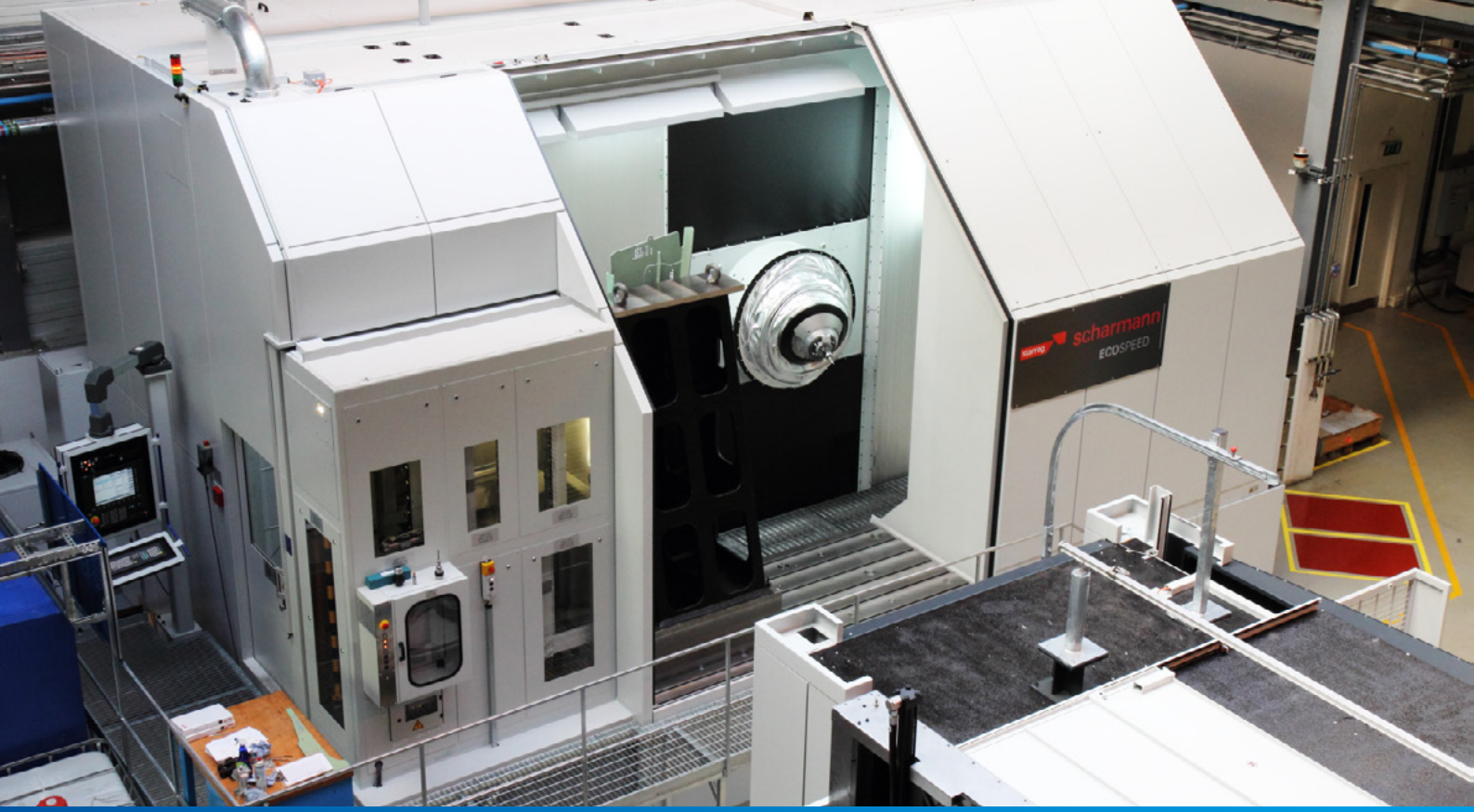
The H5 machine tool is currently undergoing refurbishment by Machine Tool Technologies.

The overhaul includes:

- Siemens 840Di controller
- Mechanical overhaul of bearings, ball screws, guideways, and other major components
- Over 200 sensors embedded around the machine tool to give comprehensive data capture capability. Sensors include vibration, acoustic emission, temperature, and strain gauge, amongst many other sensing systems.

On completion of the overhaul, tagged as 'The Full Monty', the H5 will be one of the most advanced machine tools available in the Machining Group.

Type	5-axis milling
X-axis travel	1,500mm
Y-axis travel	1,200mm
Z-axis travel	1,200mm
A-axis travel	180°
B-axis travel	Continuous
Max spindle speed	6,000rpm
Max spindle torque	11,390Nm
Max spindle power	30kW
Spindle interface	BT 50 taper
Max acceleration, linear axis	1m/s^2
Max workpiece size	800mm x 800mm x 1,350mm

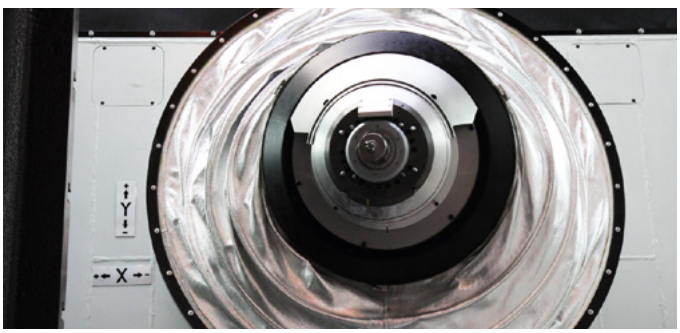


Scharmann Ecospeed

High-speed five-axis machining of monolithic aerostructures, and wet cutting of carbon fibre composites.

The Ecospeed is designed for high-speed five-axis machining of monolithic aluminium and composite aerostructures.

It features the Z3 parallel kinematic head, which can follow any path within a conical working envelope of ±40º, mounted on a column with 3.8 metre X and 2.5 metre Y-axis travel. Our machine is also specified for wet cutting of carbon fibre composites.



Type	5-axis high speed machining centre (with PKM head)
X-axis travel	3800mm
Y-axis travel	2500mm
Z-axis travel	Spindle horizontal: 670mm Spindle ±40°: 370mm In A-/B-axis, conical work envelope ±40°
Max spindle speed	30,000rpm
Max spindle torque	83Nm
Max spindle power	120kW
Spindle interface	HSK 63A-63/80
Max acceleration, linear axis	1g
Max acceleration, A/B-axis	685°/sec^2
Max jerk move	50 m/s^3
Coolant delivery type	Dual: HPC and MQL
Max workpiece size	3,800mm x 2,500mm x 370-670mm
Max table load	3,000kg
Additional functionality	Z3 PKM head for rapid 5-axis moves. Specified for wet cutting of carbon fibre reinforced polymer.

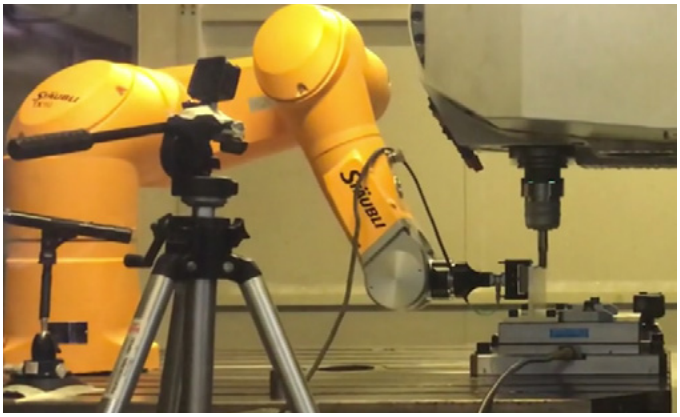
Starrag STC 1250

Flexible five-axis machine for cutting complex structural components from titanium and other high strength metals.

The STC 1250 is a flexible five-axis machine, ideal for cutting complex structural components from titanium and other high strength metals in a single set-up.

The STC modular design allows for the rapid integration of new capabilities and features, while its excellent static and dynamic characteristics provide high process stability.

Its working envelope measures 2.2 x 1.9 x 2.1 metres.



Type	5-axis machining centre
X-axis travel	2,200mm
Y-axis travel	1,900mm
Z-axis travel	2,100mm
A-axis travel	+60° to -100°
B-axis travel	360° continuous min 5.5rpm
Max spindle speed	8,000rpm
Max spindle torque	940Nm
Max spindle power	37kW
Spindle interface	HSK A100
Max acceleration, linear axis	0.3g
Max acceleration, A-axis	1 rev/s^2
Max acceleration, B-axis	0.8 rev/s^2
Coolant delivery type	High pressure through-spindle coolant at 100bar, 70 litres/min
Max workpiece size	1,250mm x 1,250mm
Additional functionality	Monitoring software and sensors.

Starrag LX 051

Single-spindle, five-axis machining centre that has been specifically designed for the high-performance milling of free-form surfaces such as gas turbine and compressor blades of varying shapes and sizes.

Equipped with a Liquid CO_2 system provided by Rother which is able to deliver CO_2, MQL and Air blast capabilities in addition to traditional emulsion coolant. The use of liquid CO_2 as a cooling agent allows for the machining of hard to machine alloys in an environmentally friendly way.

Type	5 Axis milling centre with cryogenic capabilities
X-axis travel	650mm
Y-axis travel	650mm
Z-axis travel	650mm
A-axis travel	360°
B-axis travel	-100° to +40°
Max spindle speed	18,000rpm
Spindle interface	HSK-A63
Max. workpiece weight	50 kg
Max workpiece size	490mm length
Rapid traverse	50m/min
Coolant delivery type	Through tool HPC
Controller	Siemens Sinumerik 840D

Starrag Bumotec s191

Highly accurate micromachining mill-turn centre.

Boasting 7 axis and high spindle speeds, utilising its flexible B axis to achieve small precision parts, turning, milling and grinding. The Bumotec is a Swiss designed and manufactured machine now sitting under the Starrag group and the AMRC house the only Bumotec machine in the UK to date.

The AMRC has utilised the machine for many projects so far including medical, jewellery making and defence and are keen to develop the machine further.

Type	5-axis machine
X-axis travel	400mm
Y-axis travel	200mm
Z-axis travel	410mm
Max spindle speed	30,000rpm
Max spindle power	8kW
Max spindle torque	9.5Nm
Spindle Interface	HSK-A400

Starrag Heckert X40

Horizontal 5-axis machining centre with trunnion table for milling of complex geometries in a single clamping setup. The machine is configured to suit high speed aluminium milling for applications such as finishing of cast transmission casings.

Working envelope	700 x 750 x 450 mm
Pallet dimension	400 x 400 mm
Rapid traverse rate	80 mm/min
Spindle interface	HSK63
Chip-to-chip time	2.7 s
Pallet change time	9.8 s

Starrag NB251

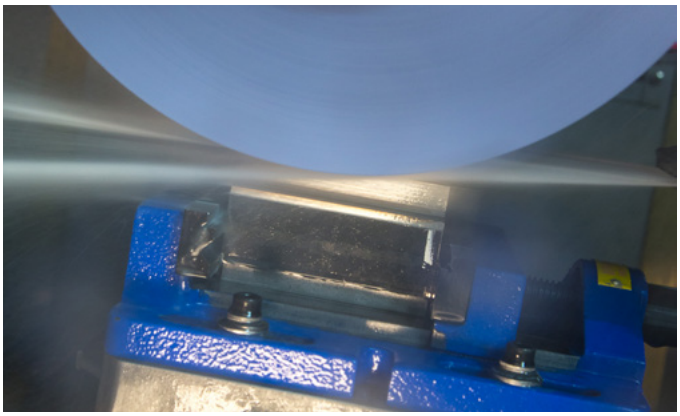
Blisk machining centre for blisks made from titanium and nickel-based superalloys. Efficient roughing for Blisks machined from solid, adaptive machining for friction welded Blisks, high dynamic finishing of the airfoils in point contact. Shortest cycle times and zero scrap rate production are achievable on the Starrag NB series. The NB series is based on the very successful Starrag LX series.

Number of spindles	1
Max. Blisk Diameter	750 mm
Linear Axes X Y Z	62 m/min
Rotary axis A	200 rpm
Rotary axis B	60 rpm
Max spindle speed	18,000 rpm
Max tool weight	6.5 kg
Max tool diameter	150 mm
Max tool length	250 mm
Standard / max. number of tools	24/62

Blohm Profimat MC607

5-axis CD creep feed grinding (CFG) platform.

The Blohm Profimat is a 5-axis CFG platform with overhead dressing capable of CD and intermittent dressing. Coolant is delivered by a programmable nozzle and the high pressure RazorTech wheel scrubber system.



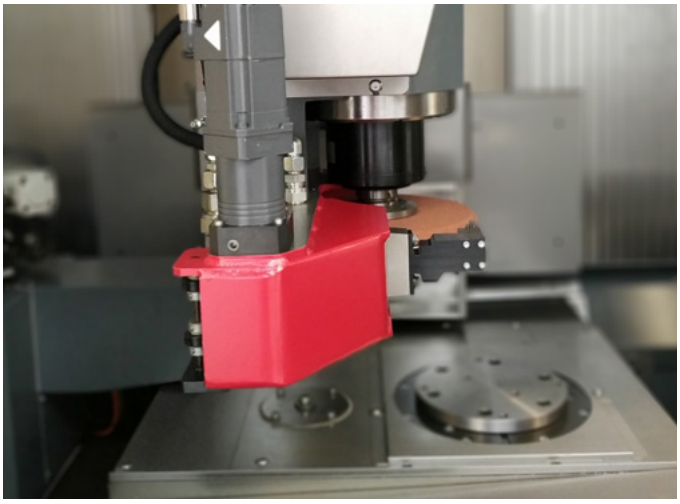
Description	5-axis creep feed grinding with overhead continuous dress and intermittent dress capability
Capacity	600 x 700 mm 50 kg maximum weight
Wheel heads / spindle	**Wheel spindles** 500 x 200 mm form 1 (127 mm bore), 52 kW, 8000 rpm **Twin overhead dresser spindles** Max. 180 mm @4500 rpm **Table mounted profile dresser unit** Max. 150 mm @4500 rpm
Coolant	Emulsion only (8 bar, 300 l/min [cooling] and 30 bar, 80 l/min [cleaning] and 4 bar, 150 l/min [dressing])
Functionality	Only grinding platform to possess continuous dressing capability in the AMRC. Machine tool platform used to develop the grindiability test method.

Blohm Prokos XT

5-axis speed stroke grinding platform.

The Blohm Prokos is a 5-axis speed stroke grinding platform with intermittent dressing. Coolant delivery is achieved via a programmable high pressure coolant system.

High axis feed rates and acceleration rates enable a speed stroke grinding approach to be adopted on complex component geometries.



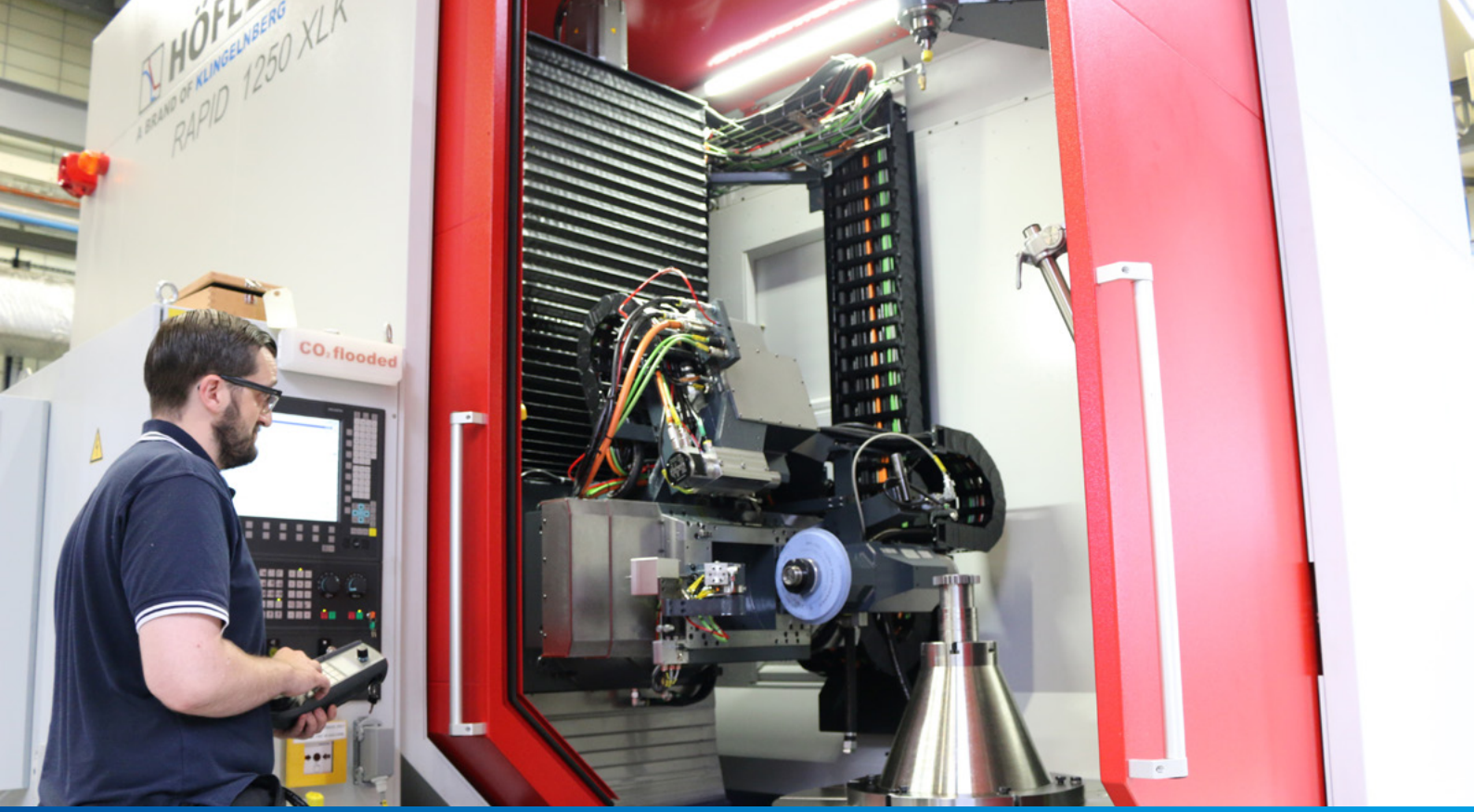
Description	5-axis speed stroke and creep feed grind with table intermittent dress capability.
Capacity	300 x 300 x 300 mm
Wheel heads / spindle	**Wheel spindles** 300x50 mm form 1 (76.2 mm bore), 25 kW, 12000 rpm **Twin dresser spindles** Max. 165 mm @6000 rpm
Coolant	Emulsion only (15.5 bar, 200 l/min [cooling] and 70 bar, 52 l/min [cleaning])
Functionality	Maximum linear feed rate [X-axis] 120 m/min at 25 m/s^2

Haas Multigrind CB

5-axis flexible grinding platform.

The haas Multigrind is a 5-axis speed stroke grinding platform with intermittent dressing and tool changeable coolant nozzles. The flexibility of this platforms enables cylindrical grinding, complex 5-axis grinding and gear grinding.

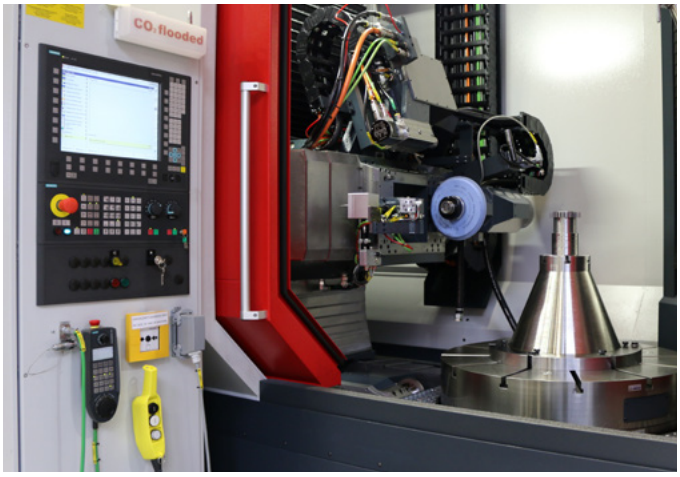
Description	5-axis multi-functional grinding platform with intermittent table dressing
Capacity	500 x Ø340 mm 340 x 25 mm form 1 (51 mm bore)
Wheel heads / spindle	**Internal spindles** 250/200/150x45/22/60 mm form 1 (51/51/20 mm bore), 30 kW, 12000 rpm **Dresser spindle** Max. 175 mm @13000rpm
Coolant	Programmable 5-80 bar delivery
Functionality	Multi use, milling compatible platform, programmed by haas Horizon software to support cylindrical grinding and surface grinding for aerospace, gear and medical components. CAM modules also allow tool and cutter grinding.



Höfler Rapid 1250XLK

5-axis gear grinding platform.

The Höfler Rapid 1250XLK is a dedicated profile gear grinding platorm. The machine is configured with a high level of SBS process monitoring capability as well as a number of software functionalities. Internal and external gears and splines are enabled using a range of advanced cutting / measurement technologies.

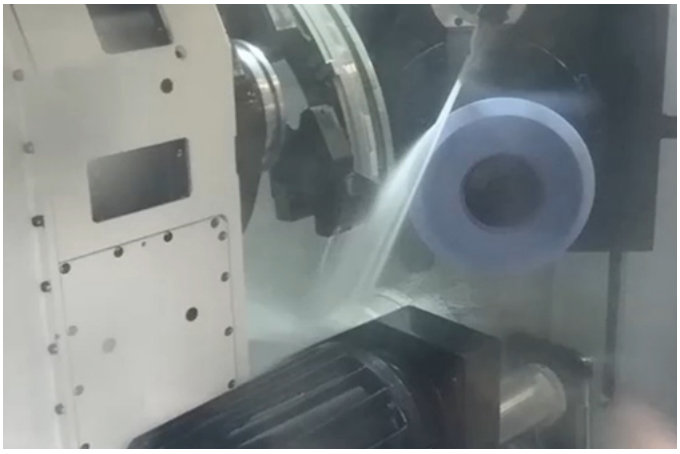


Description	Gear profile grinding capability for internal and external spur and helical spur gears.
Capacity	1250 mm maximum gear diameter 1500 mm maximum shaft length 1000 mm maximum gear face width 8000 kg maximum weight
Wheel heads / spindle	**Internal spindles** **R2 –** 250 x 40 mm form 1 (60 mm bore), 6000 rpm **R5 –** 120 x 15 mm form 1 (35 mm bore), 10000 rpm **R7 –** 80x6.8 mm form 1 (16.1 mm bore), 18000 rpm **External spindle** 300/120/75x60/30/20 mm form 1 (60/20/10 mm bore), 38.5 kW, 17000 rpm
Coolant	Neat oil only (6.5 bar, 300 l/min)
Functionality	12000mm/min maximum traverse speed Spline grinding capability OD and ID grinding capability Face coupling grinding capability

Makino G7

5-axis VIPER grinding platform.

The Makino G7 is a 5-axis VIPER grinding platform configured with an intermittent twin dresser unit. Coolant delivery is controlled via twin rotary axes and capable of delivery upto 70 bar via a range of nozzle configurations. Emulsion coolant is managed via an IFDR 4000 media free filtration system using hydra-cyclone technology.



Description	5-axis VIPER grinding with table intermittent dress capability.
Capacity	535 Ø x 400 mm. 120 kg maximum weight.
Wheel heads / spindle	**Wheel spindles** 220x30 mm form 1 (32 mm bore), 22 kW, 12000 rpm **Twin dresser spindles** 180 mm @3000 rpm
Coolant	Emulsion only (70 bar, 110 l/min [cleaning and coolant] and 5 bar, 200 l/min [dressing])
Functionality	VIPER radially programmable coolant nozzle in Pu and Pv axis.

Studer S41

Universal cylindrical grinding machine.

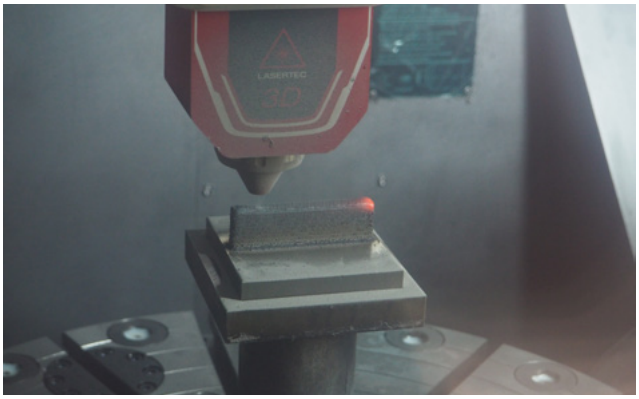
The Studer S41 is an advanced universal cylindrical grinding machine. It boasts a range of capability for both internal and external diameter grinding. Capability includes form grinding, out of round grinding and thread grinding. The machine is configured with extensive process monitoring capability and can utilise conventional and superabrasives wheels in wither emulsion or neat oil.

Description	Universal cylindrical grinding machine (OD and ID).
Capacity	1600 mm centre distance. 325 mm centre height. 190 kg maximum weight.
Wheel heads / spindle	T1 – OD HSG spindle (140m/s). 400x32 mm form 1 (127 mm bore), 30 kW, 6000 to 10000 rpm. T2 – ID spindle (45,000 rpm). T4 – OD spindle (80 m/s). 500x50 mm form 1 (50 mm bore), 15 kW, 750 to 4500 rpm.
Coolant	Emulsion and oil ready (6, 20 and 50 bar depending on wheel head).
Functionality	Precision C-axis. ID, OD, form, out of round, thread and profile grinding software capability.

DMG Mori Lasertec 65 3D

Combining laser deposition with milling and turning in one platform creating a hybrid machining centre.

It is capable of additively manufacturing using 5-axis deposition with direct energy deposition (DED). The centre has traditional machining capabilities and is able to perform 5-axis milling and turning operations. Ultrasonic machining is also a capability of the machine that allows for a more effective machining of hard to machine alloys and glass components. The platform allows faster production of complex geometries and customised parts.



Type	5-axis mill turn centre with additive and ultrasonic capabilities
X-axis travel	735 mm
Y-axis travel	650 mm
Z-axis travel	560 mm
A-axis travel	-120 to +120°
C-axis travel	360°
C-axis speed	1000 rpm
Max spindle speed	18000 rpm
Spindle interface	HSK-A63
Max. table load	600 kg
Table diameter	650 mm
Rapid traverse	40m/min
Max acceleration, linear axis	6m/s2
Coolant delivery type	Through tool HPC
Fibre laser diode	2000 Watt
Deposition rate (varies by material)	1.0 kg/h
Ultrasonic frequency	15-55 kHz
Ultrasonic Amplitude max.	10 µm
Controller	Celos Siemens Sinumerik 840D

Additional machining resources

We also have a range of smaller machining centres, housed in the AMRC Factory of the Future and Knowledge Transfer Centre (KTC), used for routine machining tasks, technology demonstrators and training.

Manual machinery

Lathes:

- Colchester Student 2500
- Huvema HU410 x 1000 (two)
- Huvema HU460 x 1500

Surface grinder:

- Seedtec YSG-52AIS

Saws:

- Huvema HU450BMSY bar saw
- Huvema KV100 vertical band saw
- Huvema HU450BMSY bar saw
- Huvema KV100 vertical band saw

Milling machines:

- Huvema HU18VS (two)
- Huvema HU24EVS
- Huvema HU 4VK-4

Cylindrical grinder:

- Jones & Shipman 1305 - Cylindrical Grinder

Oven:

- Vecstar MRF4: max temp 1,200°C, 205mm high x 305mm x 460mm

Drills:

- Ajax Pedestal Drill
- Huvema Gear Drill

Three-axis milling

Doosan DNM 6700

Type	5-axis milling (with trunion table)
X-axis travel	1,600mm
Y-axis travel	800mm
Z-axis travel	700mm
Max spindle speed	7,500rpm
Max spindle torque	610Nm
Max spindle power	22.4kW
Spindle interface	BT 50
Max workpiece size	1,600mm x 800mm
Max workpiece weight	1,814kg

Haas TM-1P

Type	3-axis milling
X-axis travel	700mm
Y-axis travel	300mm
Z-axis travel	400mm
Max spindle speed	6,000rpm
Max spindle torque	45Nm
Max spindle power	5.6kW
Spindle interface	CT 40
Max workpiece size	Table length: 1200mm Table width: 200mm
Max workpiece weight	450kg

Haas Mini Mill (two)

Type	3-axis milling
X-axis travel	400mm
Y-axis travel	300mm
Z-axis travel	200mm
Max spindle speed	6,000rpm
Max spindle torque	45Nm
Max spindle power	5.6kW
Spindle interface	CT 40
Max workpiece size	Table length: 900mm Table width: 300mm
Max workpiece weight	227kg

DMG Duravertical

Type	3-axis milling
X-axis travel	635mm
Y-axis travel	510mm
Z-axis travel	460mm
Max spindle speed	12,000rpm
Max spindle torque	100Nm
Max spindle power	11.5kW
Max workpiece weight	600kg

DMG Mori NV5000a1

Type	3-axis milling
X-axis travel	800mm
Y-axis travel	500mm
Z-axis travel	500mm
Max spindle speed	14,000rpm
Spindle interface	BT40
Max workpiece size	Table length: 1,300mm Table width: 600mm
Max workpiece weight	1,200kg

MAG CFV 550i

Type	3-axis milling
X-axis travel	500mm
Y-axis travel	500mm
Z-axis travel	500mm
Max spindle speed	8,000rpm
Max spindle torque	177Nm
Max spindle power	22kW
Spindle interface	BT 40 taper
Max workpiece weight	700mm x 500mm

Five-axis milling

Haas VF-6/50 – five-axis milling

Type	5-axis milling (with trunion table)
X-axis travel	1,600mm
Y-axis travel	800mm
Z-axis travel	700mm
Max spindle speed	7,500rpm
Max spindle torque	610Nm
Max spindle power	22.4kW
Spindle interface	BT 50
Max workpiece size	1,600mm x 800mm
Max workpiece weight	1,814kg

Turning

Haas SL40

Type	Haas SL40
X-axis travel	400mm
Z-axis travel	1,000mm
Max spindle speed	2,400rpm
Max spindle torque	1898Nm
Max spindle power	29.8kW
Max workpiece size	Cutting diameter: 600mm Cutting length: 1,100mm

MAG Hawk 300 Lathe

Type	Lathe
X-axis travel	200mm
Z-axis travel	1,000mm
Max spindle speed	3,000rpm
Max spindle power	45/37kW
Coolant delivery type	External flood coolant
Max workpiece size	400mm x 600mm
Additional functionality	External HP coolant system available

Haas TL-1

Type	Haas TL-1
X-axis travel	200mm
Z-axis travel	700mm
Max spindle speed	2,000rpm
Max spindle torque	136Nm
Max spindle power	5.6kW
Max workpiece size	Cutting diameter: 400mm Cutting length: 700mm

AMRC/

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