Market-oriented blisk manufacturing
A challenge for production engineering

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Abstract / Overview

Initially used in military low-pressure compressors (LPC) and later in high-pressure compressors (HPC), the blisk (Bladed integrated Disk) construction is increasingly found also in commercial compressors.

Fig. 1: Compressor blisk

The growing blisk market calls - not least because of increasingly global competition - for the continuous improvement of manufacturing processes and, moreover, the development of new manufacturing strategies and process chains.

Depending on blisk size, geometry and material, various competing manufacturing process chains exist. A process chain assessment tool developed by MTU permits the optimum process cycle to be found for every requirement, also involving novel manufacturing methods and new state of the art.

The major alternative process steps in blisk manufacturing are:

- Joining of blisks
- Milling from the solid
- ECM (electrochemical machining) or PECM (precise electrochemical machining)
- An integrated milling approach (strategy, tools, machines…) enables production time to be reduced 50% and beyond.
- Precise electro-chemical machining (PECM) is developing to become the preferred manufacturing approach for blisk in nickel alloys, owing to the significant savings it provides in tool costs.
- Joining processes permit blisk blades to be manufactured to suit prevailing stresses, economize material and allow blades to be replaced for repair purposes.

For each of the various manufacturing approaches, MTU Aero Engines has these past several years developed or matured processes for improved efficiency to appreciably reduce manufacturing costs, stabilize processes and enhance manufacturing quality.
Essential insights assisting these developments have been obtained under the Aviation Research Program with the aid also of university and Fraunhofer institutes.

Introduction

BLISK (Bladed integrated Disk) is a construction used for advanced heavy-duty compressor rotors in military and increasingly also civil turbine aircraft engines.
The essential advantages afforded by this integral construction are that it enables

- weight reductions (up to 30%)
- improved aerodynamics
- reductions in fuel consumption and exhaust gas volume

to be achieved.

The manufacturing challenges in the production of blisk compressors are:

- complex production processes
- considerable production effort
- stringent quality requirements
- considerable inspection effort

These challenges are aggravated by ever more demanding cost targets that can be achieved only by means of innovative manufacturing and inspection technologies.

Costs and market

As it becomes clearly apparent from the graph below, blisk manufacturing costs approximately break down into those of material, those of generating the flow duct, and those involved in other manufacturing and inspection processes.

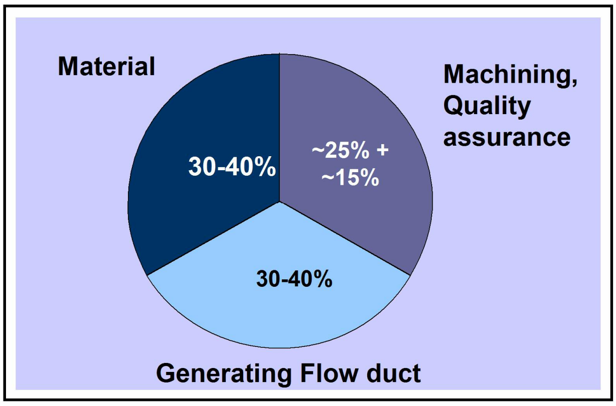


Fig. 2: Cost categories in blisk manufacture [%]

Blisk market forecasts will become apparent from the graph below.

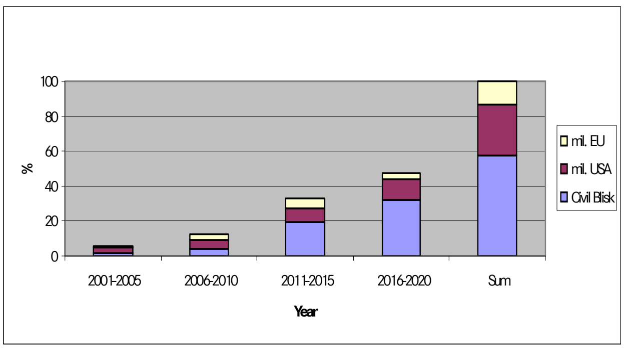


Fig. 3: Blisk market trend

Growth in the production and use of blisks becomes clearly apparent. The trend is driven also by increasing use in commercial engines.

Shown alongside are typical blisk applications on the compressors of engines powering various aircraft.
The MTU Group is presently manufacturing blisks for PW6000, EJ200, TP400, F119 engines.

Fig. 4: Blisk constructions in use

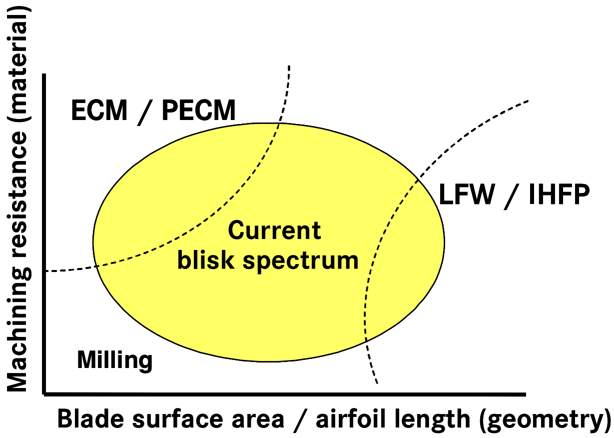
In the face of aggravating competition, individual manufacturing processes and moreover complete process chains need continuous optimization to satisfy market requirements.

Alternative process chains for manufacturing blisk airfoils

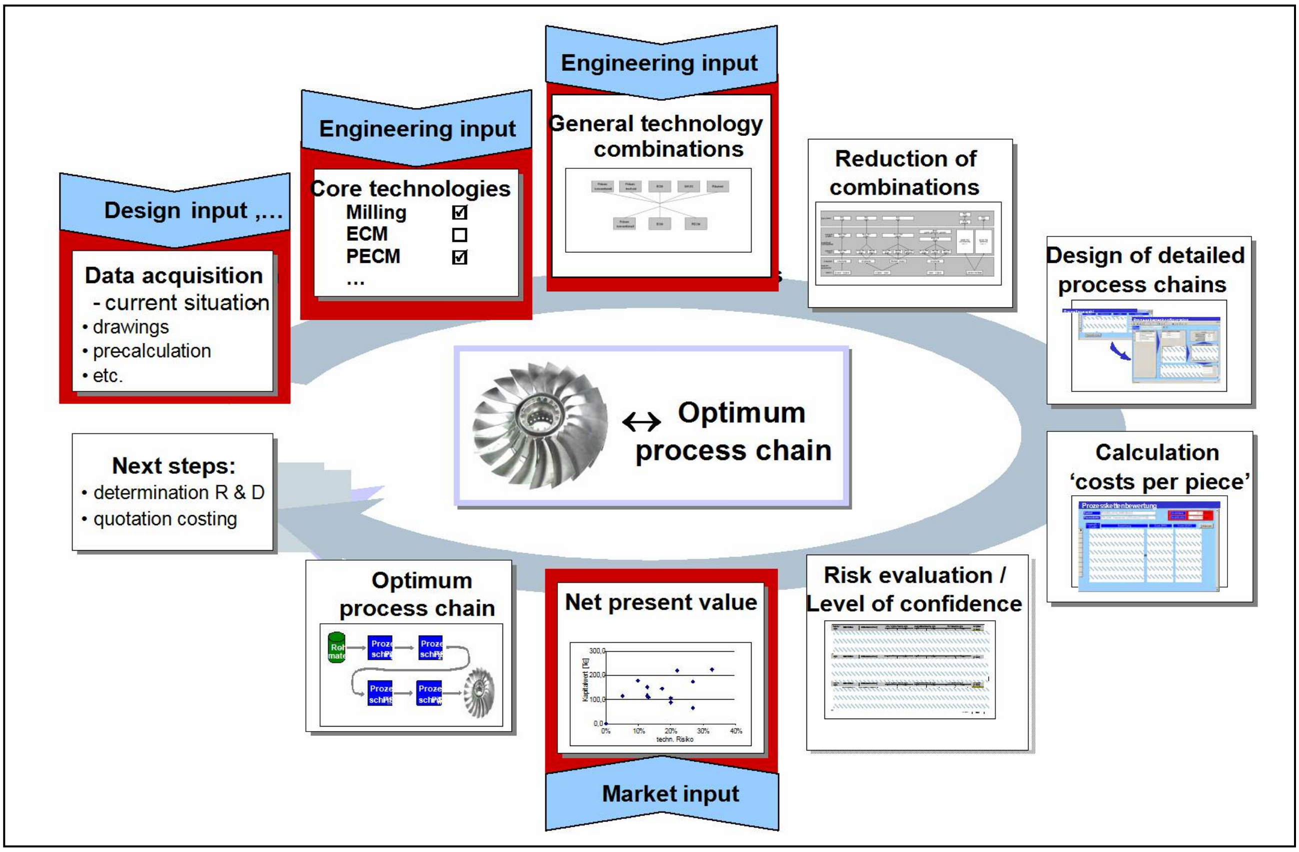
As illustrated below in a simplified presentation, the major airfoil manufacturing processes can be grouped according to airfoil size, or span, and the resistance the respective material brings to machining.

When the chamber volumes between blades are large and the blades relatively few, joining processes will be advisable to save raw material costs. In the medium-size range, all the way to the high-pressure compressor, high performance milling processes will produce best results, provided titanium alloys are used. In the hotter section of the high-pressure compressor, where difficult-to-machine Ni forging and sintered metals are used, ECM processes will prove most economical.

► Fig. 5: Manufacturing variant of blisk blades as a function of blade size and machining properties of the material.

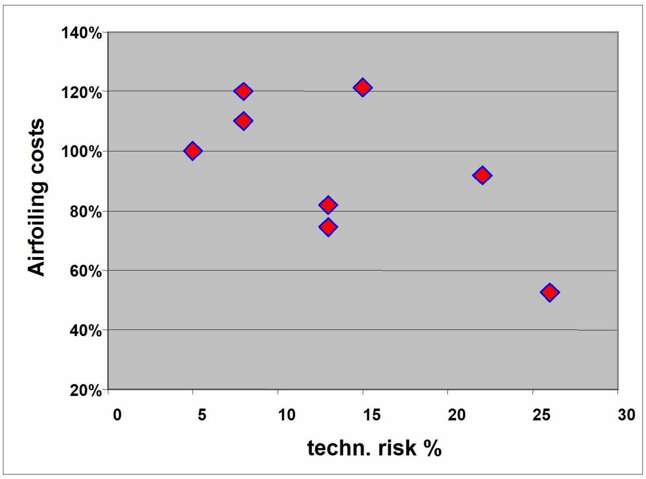


▼ Fig 6: Process chain tool for blisk manufacturing



A software-supported tool to generate and evaluate alternative manufacturing routes has been developed in connection with the development of alternative manufacturing processes for blisk airfoils. It enables the efforts and potentials of such diverse processes like milling, joining and ECM/PCEM to be evaluated.
The graph alongside shows the scatter band of manufacturing costs for a given blisk considering the diverse development and manufacturing risks attending novel or not yet optimized manufacturing processes.

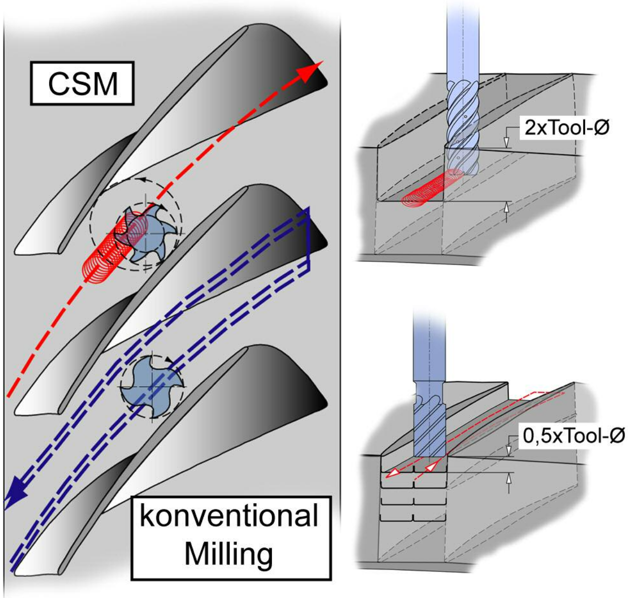
► Fig. 7: Scatter band of manufacturing costs considering the technical risk



High performance milling in blisk manufacturing

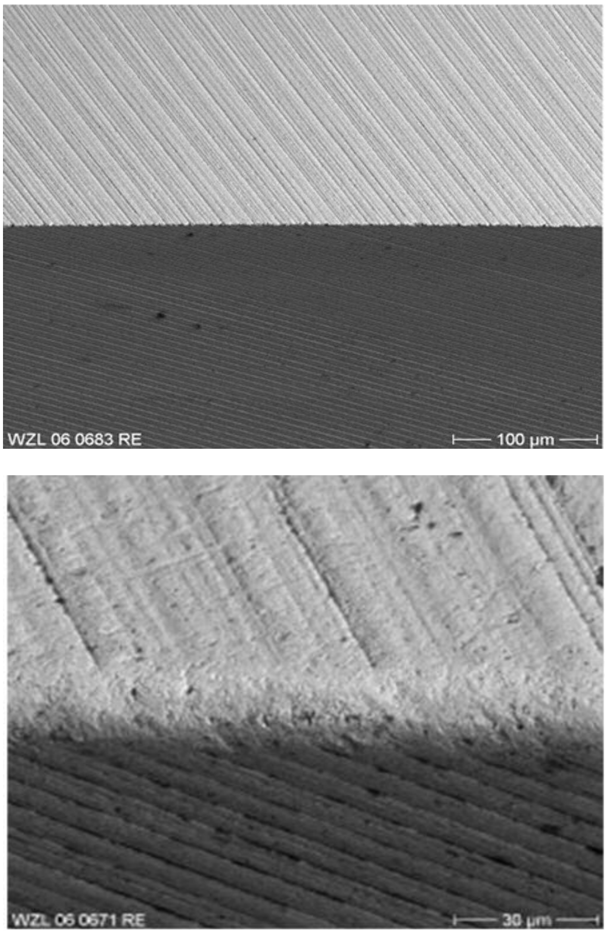
▲ Fig. 8: Blisk machining on a five-axis milling machine

Circular stagger milling (CSM) is a rough method for blisk manufacturing with a high metal removal rate patented by MTU Aero Engines. In comparison to conventional milling, with CSM the tool is moved on a *circle track,* which will be moved through the canal in-between the blades. Due to the permanent changing wideness in-between the blades the diameter of the circular track is permanent adjusted. (Roughing with finishing conditions)



▲ Fig. 9: The principle of circular stagger milling and conventional milling

The CSM-Strategy requires milling machines with a high dynamic 5-axis motion, a capable programming tool and end mills manufactured out of high performance carbide grades with special cutting edge geometry and internal coolant supply. Regarding to the high axial accelerations, which are required for CSM, the machine also should be sufficiently stiff.
Besides the extreme high metal removal rate CSM also is improving the tool life. It can be more than doubled.



▲ Fig 10: Sharp and rounded cutting edge of end mills used for blisk machining

Rounded cutting edge protects roughing tools from micro chipping. The cutting edges are displaying a uniform rubbing wear.

Tests with coated tools have not shown any improvements regarding tool live or cutting performance.

Precise electro-chemical machining (PECM) – an advanced technology for machining high-pressure compressor blisks in nickel alloys

Precise electro-chemical machining (PECM) derives from the widely used electro-chemical machining (ECM) technique.
It is characterized by very small gap dimensions between the milling electrode and the workpiece. This enables highly precise conformance of the workpiece shape to that of the cathode. PECM Processes doesn't generate any wear at the electrode, also when working on nickel alloys that are difficult to machine.
Owing to the narrow gap, exchange of the electrolyte is ensured only provided the electrode is set in an osccillating motion. In synchronism with the oscillating motion, a direct current pulse (material removal pulse) is superimposed and material is removed only when the gap is at its narrowest. This appreciably reduces the effective feed rate compared with the ECM technique.
MTU is currently adapting this technique for use on a high-pressure compressor blisk in IN718 nickel alloy.

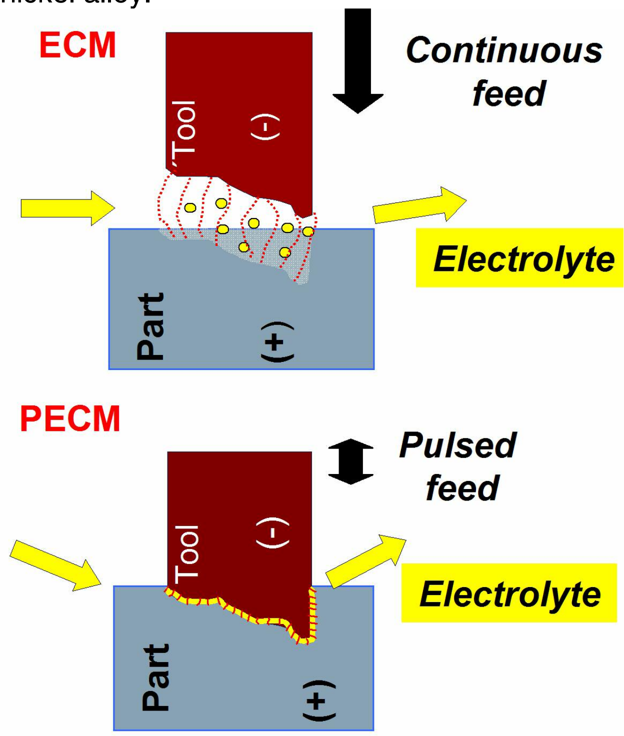


Bild 11: ECM – PECM process differences

PECM is the future manufacturing process for use on small-to-medium sized airfoils in nickel alloys.

Fig. 12: Airfoils rough-machined using ECM

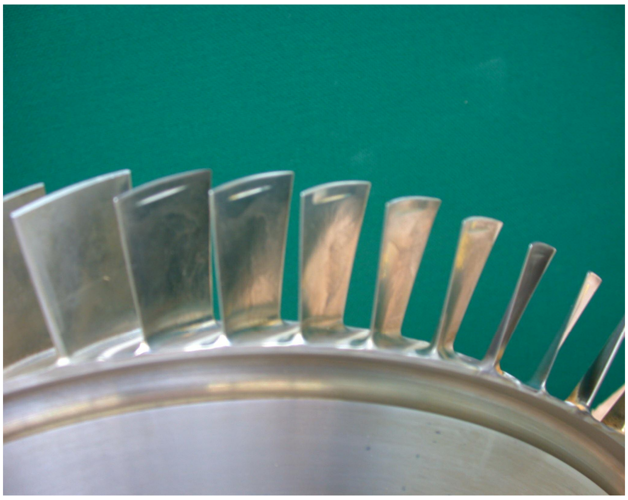


Fig. 13: Blisk blades finish-machined using PECM

In the manufacturing of nickel-alloy blisk blades a two-stage approach has proved helpful. In it, airfoils with a machining allowance are produced using a conventional ECM process. PECM is then used to generate the final shape of airfoil and annulus.

Joining technology in blisk manufacturing

The advantages afforded by a joined blisk are:

- Increased strength through ideal orientation of the forging texture of disk and blade
- Light-weight construction
- Material usage appreciably reduced
- Load-optimized material combination for disk and airfoil
- Blades can be replaced giving certain design criteria

In the manufacturing of blisks, various joining techniques are being used or under development. *Linear Friction Welding (LFW)* is a production process used to join blades to fan blisks.

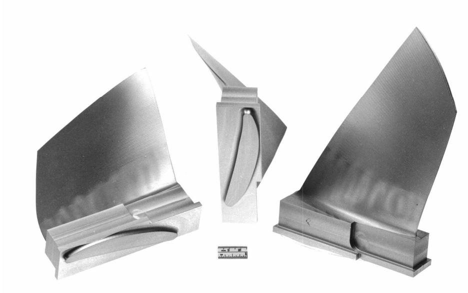


Fig 14: Precision-forged blades

Fig. 15: Hub with joining lobes

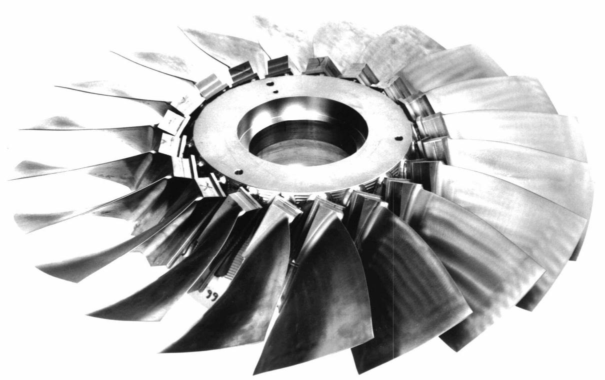


Fig. 16: LFW-joined blisk before finish machining

For use as a manufacturing and repair technique for airfoils of medium-size (cross-sectional area 200-400 sq.mm), *inductive high-frequency pressure-welding (IHFP)* is currently being developed.

In IHFP welding, the joining zone is heated by means of eddy currents generated by high-frequency excitation.

▼ Fig 17: Diagrammatic sketch of IHFP welding process.
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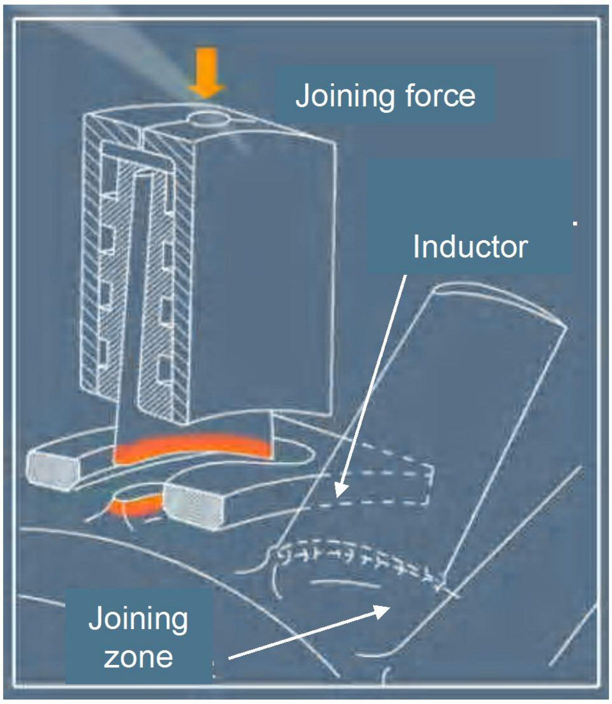


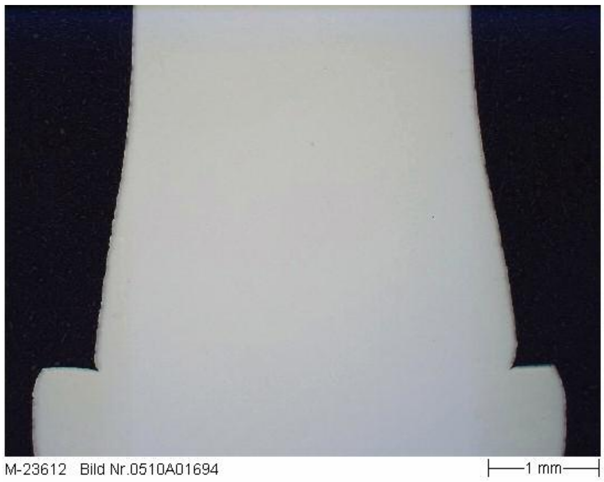
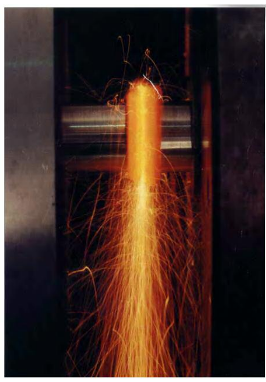


Fig. 18: Sectional view of joining zone (IHFP)

To manufacture highly-integrated compressor drums, individual blisks are welded together by means of inertia welding. This technique produces flawless, very tough joining zones such as they are indispensable for highly-stressed and life-limited components in aircraft turbine engines. However, the facilities to accommodate components of that size are extremely elaborate and costly.

▲ Fig 19: High-pressure compressor blisk drum

▼ Fig. 20: Inertia friction welding



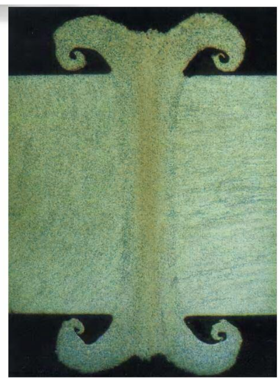


Fig. 21: Ground and polished microsection of a friction-welded joint ▲

<u>Advantages of spin friction welding:</u>

- High reproducibility
- Short welding times
- High static and dynamic strengths
- Permits joining dissimilar materials

▼ Fig. 22: Innovative SRS1000 double-spindle inertia friction welding machine