DEGREES OF FREEDOM IN TURBINE MANUFACTURING

With its multi-axis PROKOS XT grinding machine, Blohm Jung simultaneously addresses complexity, flexibility and quality issues in modern manufacturing. For maintaining the machine's volumetric accuracy of +/– 25 micron, Blohm Jung extended its volumetric compensation process, developed for conventional 5-axis machines, to a 6-axis version. IBS Precision Engineering helped them develop their procedure using the Rotary Inspector, a special wireless probe system, for measuring the three rotational axes. As Blohm Jung's launching customer, MTU Aero Engines uses the compensation software for multiple PROKOS XT machines in the manufacturing of turbine components.

Complexity and precision are two of the biggest challenges of modern manufacturing, not only in the products but also in the machine design, given the increasingly tight demands regarding the accuracy of machined products. Typically, precision is specified in the tens of microns range. In addition, flexibility is a dominant characteristic of modern, or smart, manufacturing. This refers to, for instance, low-volume, high-mix manufacturing, with small-series or even one-piece flow production and frequent product changes.

One of the consequences is that similar products and different parts of one product (family) have to be processed on different machines but have to meet the same specifications, yielding consistent quality and allowing machine-independent workpiece assignment. Combined, these challenges demand for a qualification procedure that ensures precision during operation of multiple machines. At MTU Aero Engines, for example, turbine manufacturing is a high-complexity, high-precision process requiring true 6-axis grinding (Figure 1).

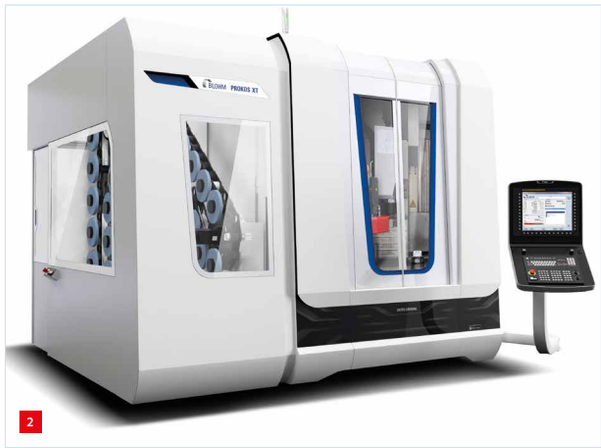
EDITORIAL NOTE

This article was contributed by IBS Precision Engineering.

Volumetric accuracy

The PROKOS XT is a recent addition to the BLOHM portfolio of surface and profile grinding machines (Figure 2). This 6-axis grinding centre was developed for the automated machining of complex workpieces and can also execute drilling and milling operations, next to grinding. The addition of a sixth axis was designed to enable the machining of complex products in one run, without changeover in clamping.

Turbine manufacturing at MTU is a high-complexity, high-precision process requiring true 6-axis grinding.



BLOHM PROKOS XT 6-axis grinding centre.

Axes of a (grinding) machine inevitably have geometric errors, originating from production and assembly of the machine itself, wear during its lifetime (backlash or bearing problems) and environmental factors in operation. The errors include radial, tangential and tilt errors in the rotational axes and guideway errors in the linear axes. Blohm Jung has developed a volumetric compensation process to minimise these errors via the control software and achieve maximum volumetric accuracy in the interaction between all six axes. This process uses Siemens VCS (Volumetric Compensation System) software to apply compensation functions to the Sinumerik machine control. The volumetric compensation process has already been used successfully with 5-axis machine tools for a number

of years. After a machine tool has been installed, all degrees of freedom of all axes are precisely measured. Compensation values are determined for the geometric errors that showed up and stored in the machine control. If the VCS software function is activated in the control, it uses these values to compensate for the errors and improve the precision of the machine. This procedure can be repeated during the operational lifetime of a machine.

Partner profiles

Blohm Jung GmbH
The product portfolio of Blohm Jung GmbH extends from surface grinding machines through application-oriented universal machines to customer-oriented production machines. The experience gained from over 35.000 delivered machines worldwide, combined with service and technology specialists that support customers throughout the entire lifecycle of their machines, ensure great production efficiency. The brands BLOHM and JUNG are members of the United Grinding Group, headquartered in Bern, Switzerland.

WWW.BLOHMJUNG.DE

MTU Aero Engines AG
Headquartered in Munich, MTU is Germany's leading engine manufacturer, engaging in the development, manufacture and support of commercial and military aircraft engines in all thrust and power categories and industrial gas turbines. MTU's focus is on low-pressure turbines, high-pressure compressors and turbine centre frames. Core competencies include high-tech manufacturing, maintenance techniques, inspection and testing expertise, as well as comprehensive systems knowledge.

WWW.MTU.DE

IBS Precision Engineering
Headquartered in Eindhoven (NL), IBS Precision Engineering is a specialist in precision metrology and the development of machines and modules for ultra-precision applications. They supply measuring systems and components for, amongst others, semicon, aerospace, automotive and machine tool markets. For specialised needs, IBS designs and delivers product measurement machines and scientific instruments. Traceable accuracy down to the nanometer scale, application of latest standards and ground-breaking technology is offered.

WWW.IBSPE.COM

Rotary Inspector hardware. (Photos: Nicole Minneboo, IBS)
(a) The Trinity measuring head.
(b) The master ball (shown on an EROWA mount).

A first on 6-axis machines

Applying the volumetric compensation procedure to the 6-axis PROKOS XT machine, however, was new to Blohm Jung and posed two challenges; the acquisition of the error data and the algorithms for converting these data into compensation settings for the machine. Concerning suitable measuring systems for precise acquisition of error data, for the linear axes a straightforward solution was selected; a laser measurement system capable of measuring errors

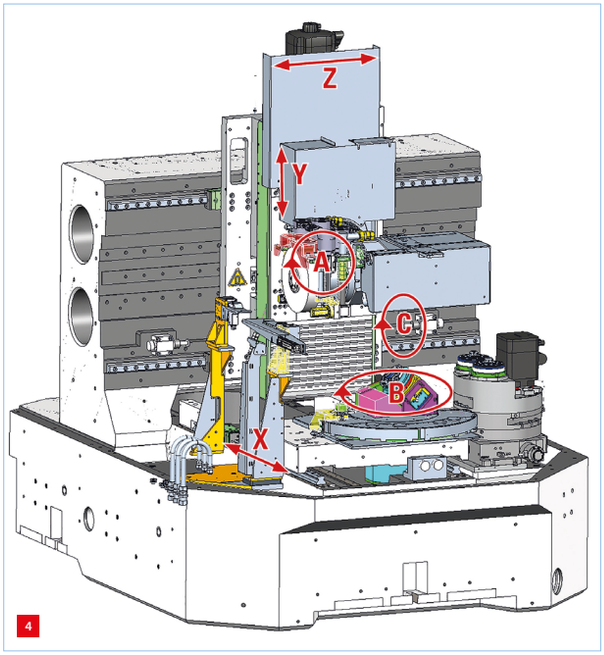
in six degrees of freedom along a linear axis. Measuring the three rotational axes, however, had no precedent.

For measurement of the three rotational axes, MTU introduced Blohm Jung to the Rotary Inspector solution from IBS Precision Engineering, which can provide confirmation of the true positioning accuracy of a tool relative to the workpiece for (normally) 5-axis machines, under dynamic conditions. Mimicking normal operation of a machine, the Rotary Inspector can check the volumetric accuracy of all machining axes by moving them simultaneously.

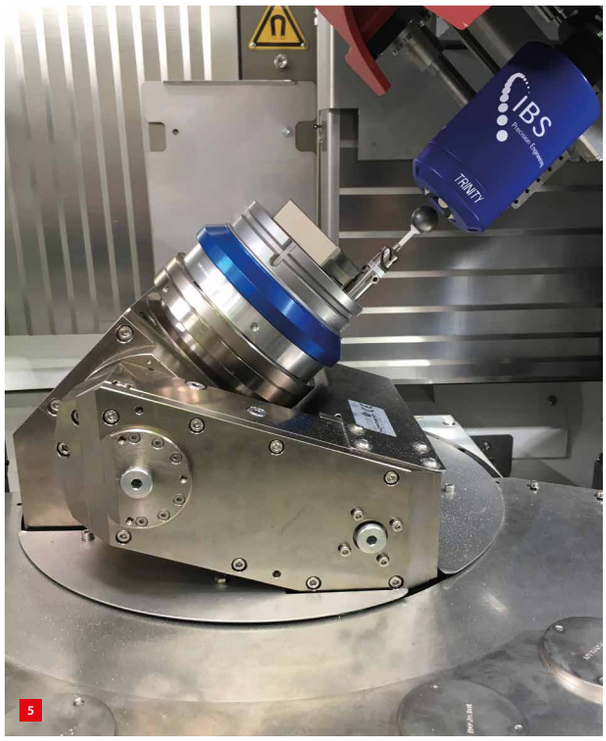
Rotary Inspector

IBS had designed the Rotary Inspector to determine (and correct) critical geometric and dynamic performance parameters of 5-axis machines. Based on measurements according to the ISO 10791-6 standards, the Rotary Inspector measurement software can determine the total 5-axis machine tool accuracy within minutes and also calculate the pivot line offsets and squareness errors. Extensive measurement results can be condensed into two characteristic numbers; the Q value as the maximum geometrical error, providing an upper boundary for the dimensional accuracy, and the P value as the largest dynamic error, representing the surface finish.

The Rotary Inspector (Figure 3) includes a Trinity wireless measuring head, which is placed in the spindle, and a master ball, which can be placed on the product table using an optional EROWA mount for accurate positioning.



Schematic of the 6-axis PROKOS XT machine showing the three linear axes (X, Y and Z) and the three rotational axes (A, B and C).



The first application of the Rotary Inspector for measuring a 6-axis machine.

Coordinate transformations

The biggest challenge in developing the 6-axis application was not only the measurement of all six axes, but the interpretation of the measurement results and their translation into compensation values, requiring a thorough understanding of the construction of the machine. The Rotary Inspector solution covers a total of 21 standard 5-axis machine types/configurations. This was the first application of the Rotary Inspector for measuring a 6-axis machine.

The PROKOS XT configuration (Figure 4) features three linear axes (X, Y and Z) and three rotational axes (A, B and C); it can be considered as a 5-axis machine with an additional tipping axis (C) sitting on the B-axis under an 45° inclination angle. Naturally, this adds to the complexity of defining the required coordinate transformations. Errors measured in the measuring head coordinate system have to be transformed to errors in machine coordinates (such as squareness and position errors of the rotary axes) and subsequently converted into an optimisation of the kinematic chain in the machine.

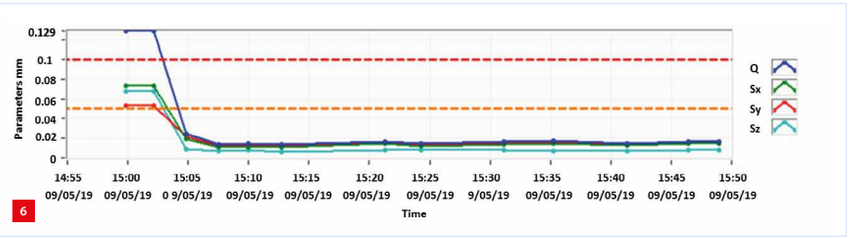
An additional challenge was posed by the nature of the machine. The PROKOS XT uses a bulky grinding tool mounted on a short spindle, in contrast with the conventional milling machine which has a slender tool mounted on a long spindle. This means that on this 6-axis machine the various linear and rotational axes have a limited range and not all standard motion sequences are

accessible, as the measuring head under certain conditions could collide with the index table and workpiece carrier. Therefore, some of the measurements have to be performed in non-standard situations.

ISO philosophy

In the Rotary Inspector formulation, the PROKOS XT has been defined by the combination of two 5-axis types that best represents the 6-axis configuration. The measurement procedure then combines the standard tests for these two types, covering the A and B and the A and C axes, respectively, and finishes with a comprehensive ABC test.

Based upon the reasoning behind the ISO 10791-6 standards (Test conditions for machining centres – Accuracy of speeds and interpolations), the various elements of this test, for example one rotary axis moving with double the speed of the other axis or one axis moving in positive direction and the other in negative direction, have been merged into the 6-axis test. This does not make the 6-axis test 'ISO-certified', as there is no 6-axis ISO standard, but it represents the best approach following the ISO philosophy. In this way, a major step towards the reliable qualification of 6-axis machines has been taken.



Typical Rotary Inspector output, showing the evolution of the Q value, i.e. the maximum geometrical error, and the underlying maximum individual axis errors (Sx, Sy and Sz). The sharp decline in all values reflects the error compensation taking effect.

Partner quotes

Blohm Jung: "Unique selling point"

"MTU was our launching customer for the 6-axis PROKOS XT machines. They introduced us to IBS and we decided to collaborate to integrate their Rotary Inspector in the VCS volumetric compensation process. With the aid of Blohm Jung's new VCS procedure, customers can use 6-axis grinding machines flexibly for the production of various products and parts of product families. Now they can improve not only the volumetric accuracy of their machine using the VCS, but also the comparability and consistency between different machines, as well as ensure high technological availability with constant workpiece quality.

"Currently, the VCS is a USP of Blohm Jung. We plan to further strengthen our position in the high-end grinding and profiling market by integrating volumetric compensation into our service offerings; for instance, checking the volumetric precision and applying the required compensation will be an integral part of maintenance intervals. Also, the VCS will be added to other products in our portfolio case by case."

Matthias Guhlke, senior key account manager Turbine at Blohm Jung, Hamburg

MTU: "The step from 5 to 6 axes"

"For calibration of our machine tools we have been working with the Rotary Inspector and Spindle Check tools from IBS for two years now. Today, the complex geometry of workpieces requires a 6-axis grinding machine and for this we needed a 6-axis calibration procedure, to ensure 25-micron accuracy over the full working range of a machine. We had to develop a dedicated procedure, in collaboration with machine builder Blohm Jung, machine control supplier Siemens and metrology expert IBS.

"Our operators regularly test their machines using simple touch probes. When any deviations show up, such as vibrations or incorrect parameter settings, our measurement engineers come in to conduct a VCS volumetric compensation procedure. They use a Renishaw XM60 laser to check the straightness and the orthogonality of the linear axes and the Rotary Inspector for checking the kinematics of all six axes.

"Currently, we have three 6-axis grinding machines in operation and a fourth and fifth one are underway. Thanks to the Blohm Jung VCS process employing the IBS Rotary Inspector we can manufacture products with consistently high quality and precision on all of these machines."

Matthias Scherm, Plant Services-Engineering at MTU Aero Engines, Munich

IBS: "Trusting the machine"

"Machine builders as well as users can apply our Rotary Inspector solution for qualifying their machine and performing acceptance tests. The Trinity measuring head literally 'sits' on the machine, undergoing all movements that occur during live machining – and in the present case it is really the six axes moving simultaneously. Laser measuring set-ups do not allow this kind of dynamic measurement. The measurement is completed in minutes and the procedure can be conducted on a regular basis, for example weekly or monthly, and also ad hoc, depending on the workload or after a crash.

"As the Rotary Inspector covers all six axes under operational conditions, the calibration gives the user confidence in their machine. They know they can trust their machine; it is within specification regarding volumetric accuracy and the machine control is doing what it should do.

"Being a Siemens Product Partner enables us to bring together the Rotary Inspector measurement expertise with their machine compensation software. We were delighted to support Blohm Jung, and hence MTU, with the introduction of their ground-breaking machine."

Theresa Spaan-Burke, innovation director, and Joris Janssenswillen, system engineer, at IBS Precision Engineering, Eindhoven