Levicron GmbH
Sauerwiesen 6
D-67661 Kaiserslautern
Tel.: +49 (0) 6301 – 718 57 25
Fax: +49 (0) 6301 – 718 57 56
info@levicron.com
www.levicron.com

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- **ASD-H25/Cx** – Spindle design for subcritical spindle operation to rated speed
- **ASD090H25 / ASD060H25** – The crucial question: Speed or stiffness for milling and grinding applications?
- **ASD-Px** – Zero-point tooling chuck and double-encoder feature for our work-holding spindle
- **Exhibitions** – Levicron exhibits at Optatec and EPHJ
- **Employments** – Levicron has employed to support production control and marketing

ASD-H25/Cx – Spindle design for subcritical spindle operation to rated speed

Resonance modes and bearing stiffness

Assuming the turning frequency stays below the shaft bending critical frequency the rotating shaft can be considered to be rigid and suspended in the bearing stiffness and damping. As a result a conical as well as a cylindrical resonance mode around the inertia midpoint of the rotating mass can be derived according to Fig. 1.

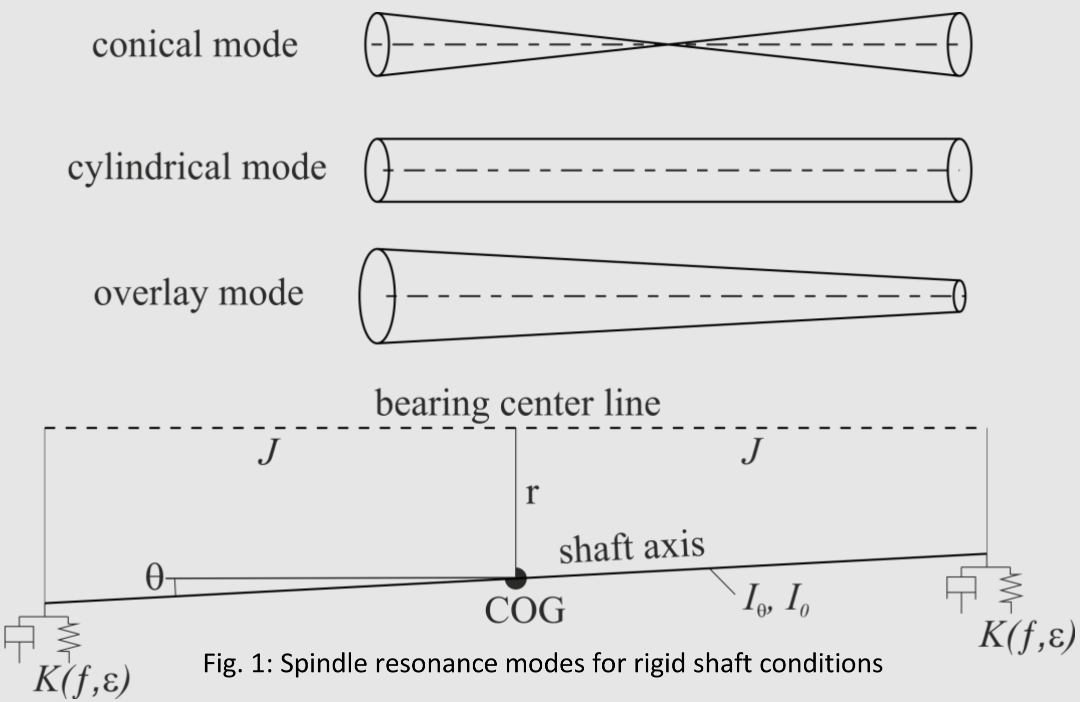


Fig. 1: Spindle resonance modes for rigid shaft conditions

Together with the rotating mass *M* and its moment of inertia *J* the radial bearing stiffnesses *K* determine the resonance frequencies of the bearing-shaft system, the bearing damping *C* their amplitudes. It is obvious that a heavier shaft would lead to a lower cylindrical resonance frequency, a longer shaft on the other hand to higher conical resonance frequencies.

The stiffness of gas bearings is proportional to the reciprocal value of the square of the bearing gap width. Means, with half the bearing gap size four times the stiffness would result.

With common diameter over gap ratios of 0.0001 to 0.0007 this means that a journal bearing with 50 mm in diameter requires a bearing gap size of 10 - 35 microns for a sufficient bearing stiffness.

For a sufficient load capacity on the other hand predominantly bearing the diameter and length are supposed to be as large as possible what again leads to larger shaft diameters compared to roller bearing spindles.

Changing bearing stiffness over speed

High-speed air bearing spindles are designed to operate at their centrifugal load limit when running at their rated speed where shear velocities of up to 250 m/s in journal bearings and 450 m/s in thrust bearings are common. Along with these shear velocities (=shear losses) and centrifugal loads a bearing gap reduction of 50 – 80 % of their static size at stillstand in journal bearings occur. The radial shaft expansion and bearing deformation at speed due to centrifugal and thermal loads are shown in Fig. 3. Consequently radial stiffness of air bearing spindles and thus rigid mode resonance frequencies rise with speed and are a function of such. Fig. 2 shows a stiffness field of an aerostatic journal bearing with speed and relative shaft eccentricity where $\varepsilon = 0$ means the shaft rotates concentric and $\varepsilon = 1$ that it just touches the bearing.

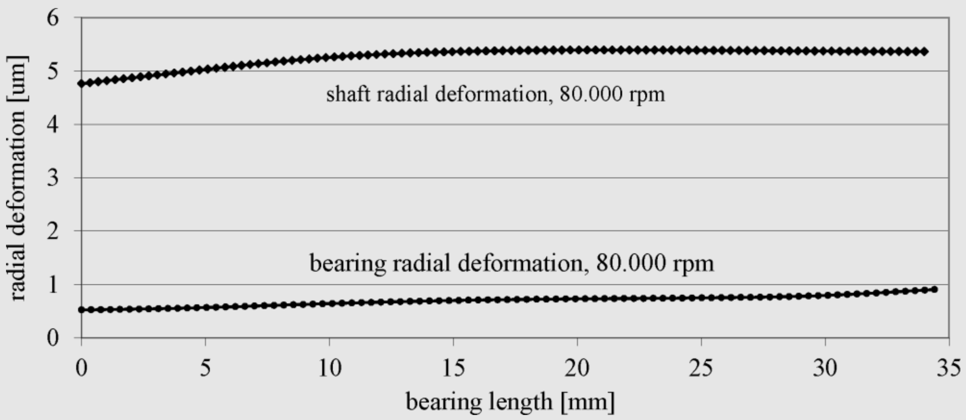


Fig. 2: Radial shaft and bearing deformation due to centrifugal and thermal loads

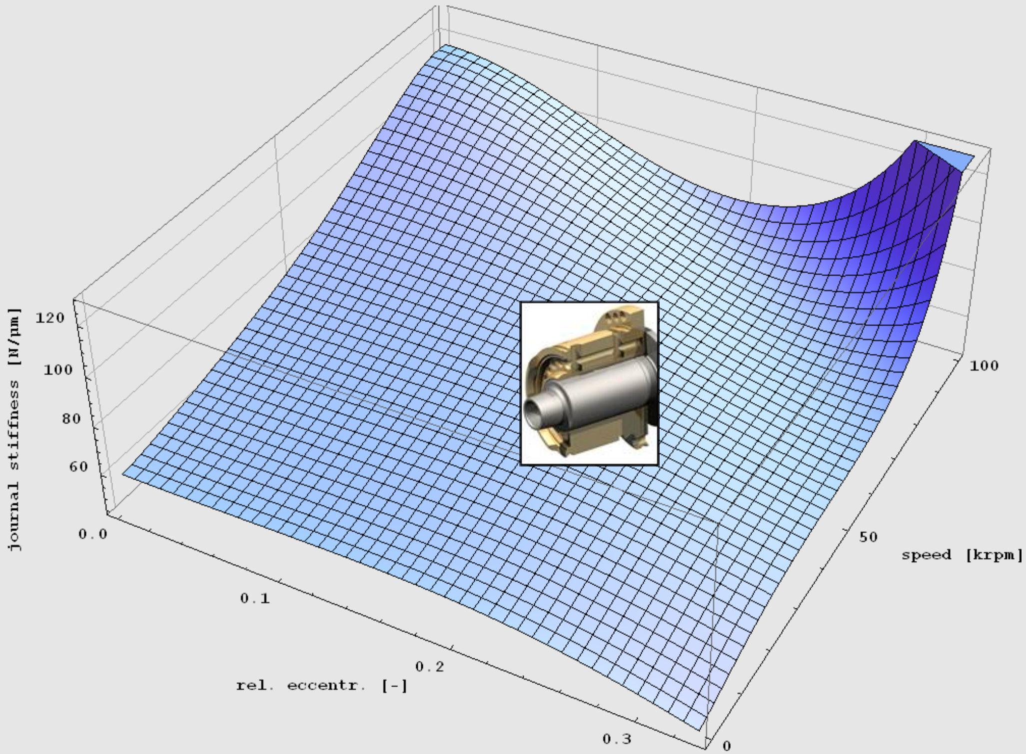


Fig. 3: Radial stiffness of a journal baring with speed and relative shaft eccentricity

Rotor dynamics and stability of aerostatic spindles – rigid modes

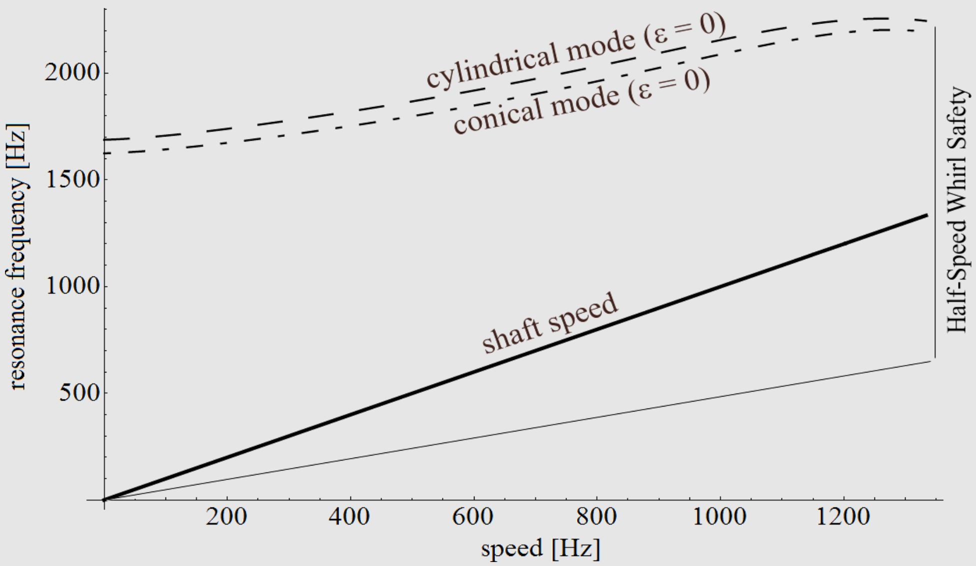


Fig. 4: Resonance and stability chart for rigid-shaft model

Leading back the speed dependent radial stiffnesses into the shaft-bearing-model shown in Fig.1 allows a calculation of the mode-depending resonance frequencies and the stability field of a spindle with speed according to Fig. 4. Whenever the shaft speed (Hz) crosses or gets close to a resonance frequency within a +/- 10 % band significantly increased dynamic run-outs at the tool and vibrations can be measured and are to be avoided for precision machining.

Verification and spindle dynamics measurement – sub-critical spindle operation up to rated speed for all of our ASD-H25 and ASD-Cx

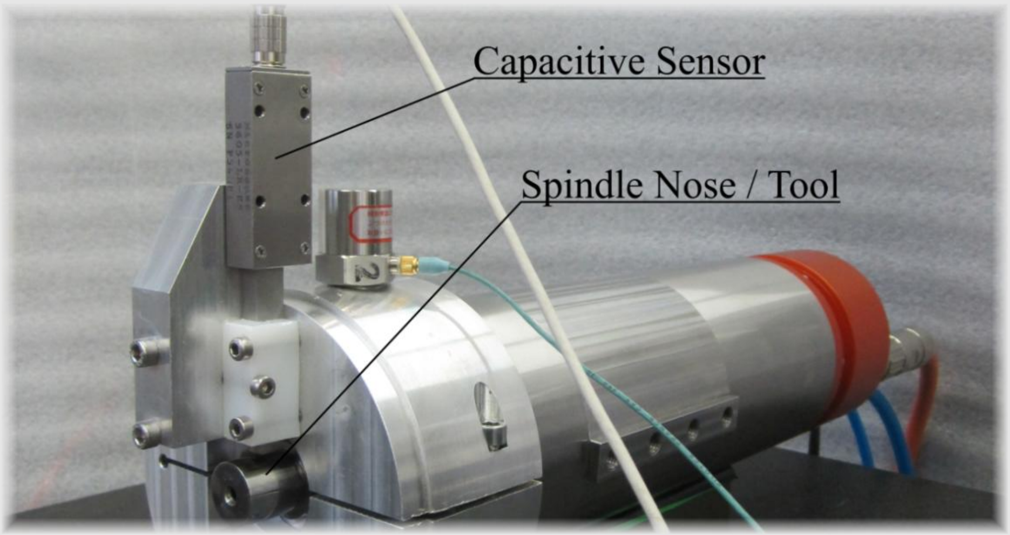


Fig. 5: Measurement setup to determine spindle resonances with speed

With actual capacitive sensors the distance signal between the sensor and a rotating tool can be recorded with a bandwidth of up to 120 kHz and 2 nm resolution (Fig. 5). The signal itself can be split into its harmonic portions by FFT filtering what gives a standard frequency spectrum for a certain speed. Taking a continuous frequency spectrum measurement with speed during ramping a spindle up/down leads to a 3D waterfall FFT spectrum with speed which is shown in Fig. 6 as top view for our ASD080H25. In here lighter areas represent resonance modes of the shaft itself or the shaft-bearing system as well as the turning frequency which is excited by residual imbalances.

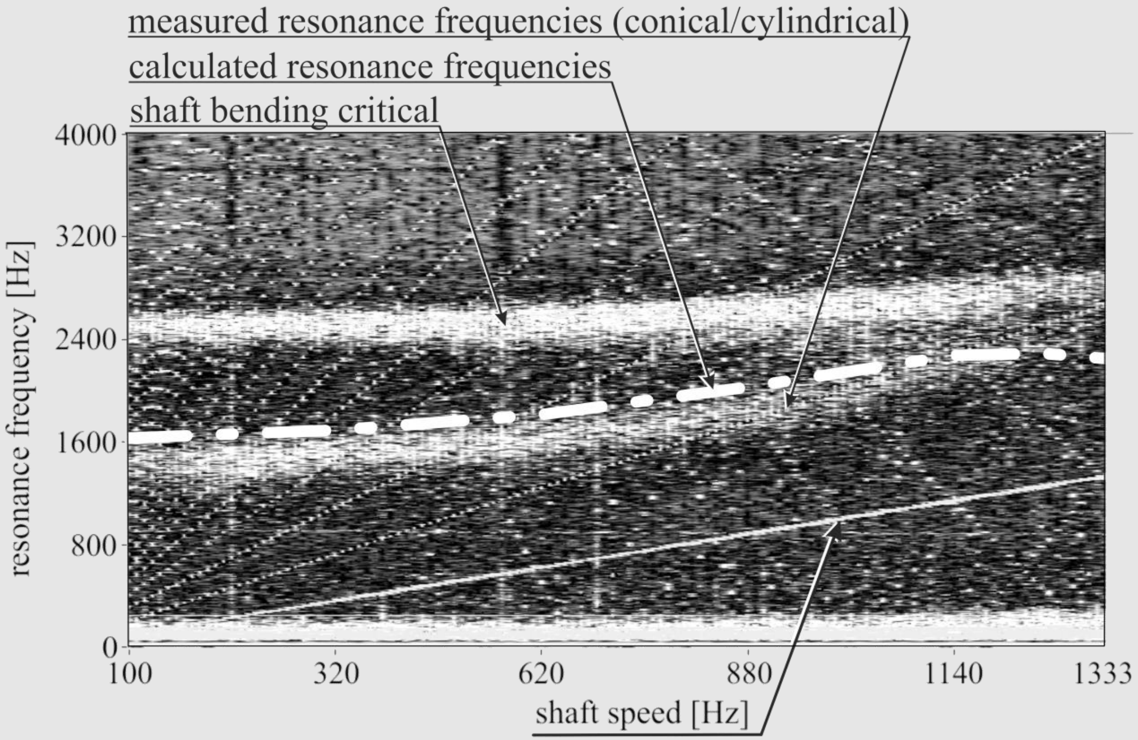
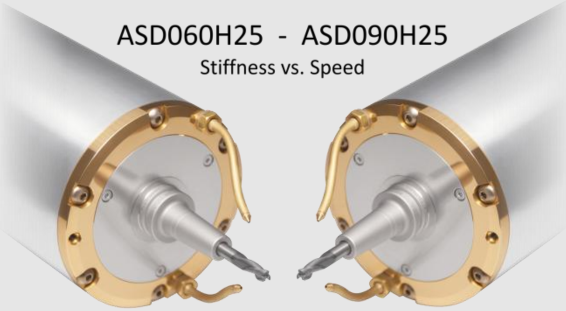


Fig. 6: ASD080H25 - spindle resonances with speed

In Fig. 6 also the calculated resonance frequency modes are plotted. It can be seen that at no condition the turning frequency (horizontal axis) is close to any natural frequency and verifies that the spindle can be used sub-critical through its whole speed range. This again avoids high dynamic run-outs and vibrations when crossing or operating the spindle within a resonance area.

The calculated resonance modes – conical and cylindrical fall together in this case – are slightly higher at lower speeds as for the calculation no transient but a warmed-through spindle condition was assumed. The measured resonances on the other hand are recorded from cold at standstill to warmed-through at rated speed. However the resonance frequencies at higher speeds show slightly higher values what can be explained by the aerodynamic portion of the rotation to be assumed to too small. However the prediction of the dynamic behaviour is within +/- 5 % accuracy. Knowing or measuring the residual static and dynamic imbalances of the shaft even allows a precise calculation of the dynamic run-out at tool when running a spindle below its shaft bending resonance.

ASD090H25 / ASD060H25 – The crucial question: Speed or stiffness for milling and grinding applications?



Our air bearing spindle type ASD-H25 is available with rated speeds of 60.000, 80.000 and 90.000 rpm and are identical except from the bearing parameters. As stated before higher speeds mean higher centrifugal loads and shear losses and thus a bigger change in bearing gap height with speed which can be 50 – 80 % of the static gap size. Fig. 7 shows the calculated transient bearing gap reduction with speed of a real spindle bearing where only 40% of the static gap size remains at 150 krpm.

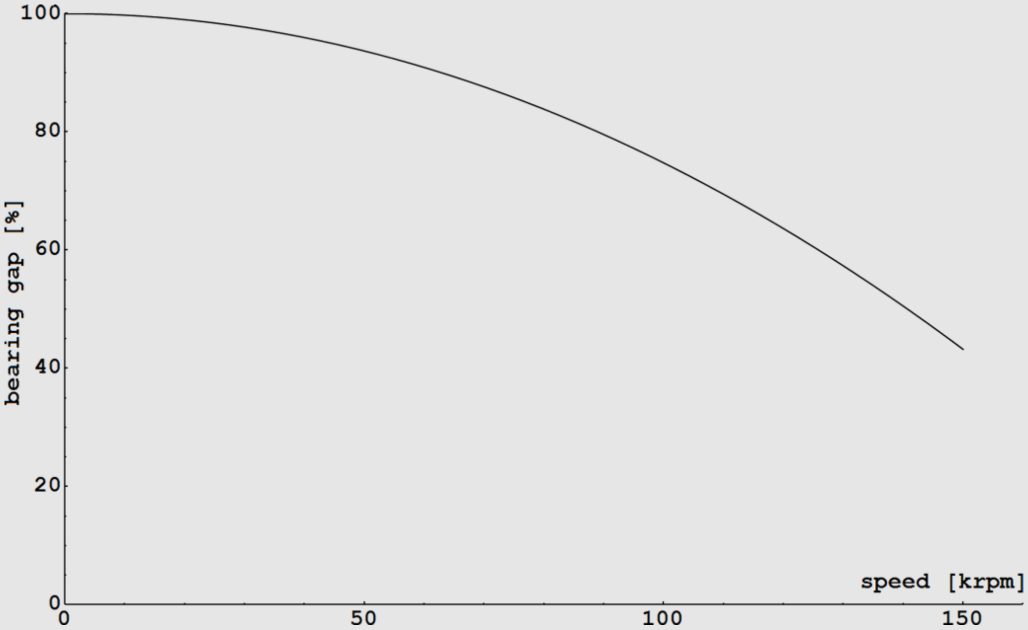


Fig. 7: Gap reduction of a journal bearing with speed

Consequently the bearing gaps of a spindle with a higher nominal speed need to be larger than those for a spindle with lower speeds to ensure a sufficient gap size at top speed. As the stiffness of a gas bearing – means the increase in load capacity with radial shaft deflection – is a reciprocal function of the square of the bearing gap height an increase in gap size of 40 % would lead to a reduction in stiffness of about 50 %. While all of our ASD-H25 models offer about the same ultimate load capacity and radial bearing stiffness at their rated speed the static radial stiffness at standstill is lower for models with higher rated speeds as shown in the spindle property table below.

		ASD060H25	ASD080H25	ASD090H25
Radial ultimate load capacity at spindle nose (static, standstill)	*[N]*	330	300	290
Radial stiffness at spindle nose (static, standstill)	*[N / µm]*	50	30	25
Radial stiffness at spindle nose (static, rated speed)	*[N / µm]*	76	83	87

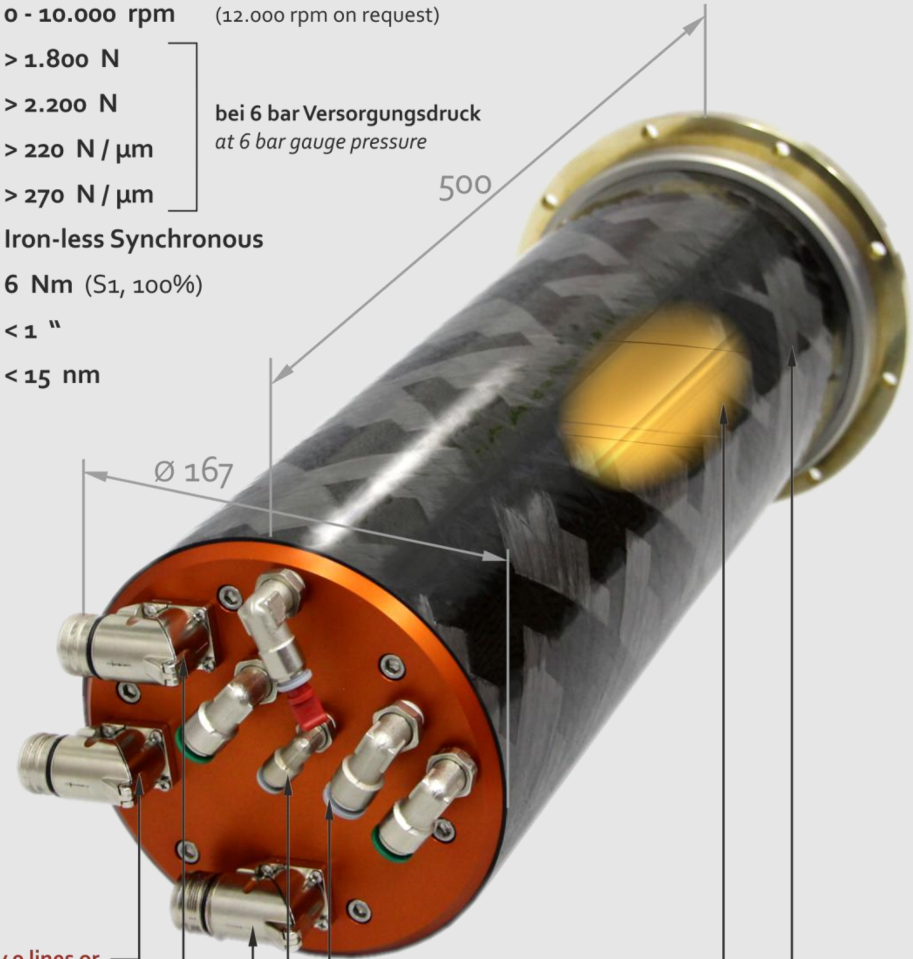
Only a stronger aerodynamic effect for higher speeds makes a difference for the radial high-speed stiffness at spindle nose.

Ultimately the application determines the choice of the right spindle model. Where for machining steel molds a higher bearing and damping is way more important than speed for engraving with small tools the opposite is the case.

During intensive cutting tests at customer sites it turned out that stiffness and thus damping often leads to a better surface finish and dynamic run-out as long as lower feed rates are acceptable.

ASD-Px – Zero-point clamping chuck and double-encoder feature (253 lines GMR + 11.840 lines optical 1VSS or 26bit optical absolute)

Speed / *Drehzahl* :	**0 - 10.000 rpm**	(12.000 rpm on request)
Radial load capacity / *Radiale Tragfähigkeit* :	**> 1.800 N**	**bei 6 bar Versorgungsdruck** *at 6 bar gauge pressure*
Axial load capacity / Axiale Tragfähigkeit :	**> 2.200 N**	
Radial stiffness / *Radialsteifigkeit* :	**> 220 N / µm**	
Axial stiffness / *Axialsteifigkeit* :	**> 270 N / µm**	
Motor type / *Motorart* :	**Iron-less Synchronous**	
Motor torque / *Motordrehmoment* :	**6 Nm** (S1, 100%)	
Angular accuracy / *Positioniertreue* :	**< 1 "**	
Error in Motion / *Rotationsgenauigkeit* :	**< 15 nm**	



Patented Bearing Technology
Patentiert Lagertechnologie

Work-holding options:
- **Face plate**
- **Vacuum Chuck**
- **Zero-point clamping chuck**

Aufspannoptionen:
- *Planscheibe*
- *Vakuumfutter*
- *Nullpunktspannfutter*

High-resolution 1VSS optical encoder with 11.840 lines or 26bit BISS-C, DRIVE-CLiQ, Fanuc, Panasonic comp. absolute encoder
Hochauflösender optischer 1VSS Encoder mit Strichzahl 11.840 oder 26bit Absolut-Encoder mit BISS-C, DRIVE-CLiQ, Panasonic Protokoll

1VSS GMR encoder with 253 lines
1VSS GMR Encoder mit Strichzahl 253

Ultra-low vibration iron-less synchronous motor with 6 Nm torque (S1)
Dynamikoptimierter Synchronantrieb mit Luftspaltwicklung und 6 Nm Drehmoment (S1)

Rotary feedthrough for vaccum and pressurized air
Vakuum- und Druckluftdrehdurchführung

High-efficiency thin-film liquid cooling
Hocheffektive Dünnfilm-Flüssigkeitskühlung

Cartridge Design for closed head stocks
Patronendesign für geschlossene Spindelstöcke

Exhibitions – Levicron exhibits

Optatec, Fankfurt, May 20^{th} – 22^{nd}

Stand / booth J47

EPHJ, Geneva, June 17^{th} – 20^{th}

Employments – Levicron has employed to support production control and product marketing

Along with the growth of our international sales activities and the continuous expansion of our customer and product portfolio we are delighted to welcome Mr. Dennis Keck from May 15^{th} on to support our team in the fields of production control and quality assurance.

Furthermore international marketing strategies are being worked out by several student workers we hope to welcome in the future to join our team.