

# 轴承分析

对轴承动力学进行深入细节的分析提高了性能加快了研发速度  
撰文/ 崔斯顿·汉尼威

## Bearing analysis

Detailed analysis of bearing dynamics improves performance and cuts development times

By Tristan Honeywill

**适**当的软件对于消除产品研发过程的主观臆测是非常重要的，这点在摩擦力非常复杂并且很关键的动力传动系统中尤其显得正确。开发样品变速器是昂贵并且费时的，但是任何遗漏问题如果带到正式生产过程中都会带来更大的损失。

今天，要想成为一个成功的供应商，你必须使用尽可能多的传统的标准分析套件。但要想成为行业翘楚，许多厂家开发他们自己的软件以更加全面地了解他们的产品，并且为他们的客户提供更完善的技术支持。

INA-Schaeffler一家德国公司，已经将这种方法使用了一段时间了。这家公司是滚动轴承及发动机用零件专业供应商，使用许多内部软件包以提升研发过程。

“由于市场上没有能够满足我们需要的现成产品，所以我们开发了Bearinx, Simpl及CABA这些内部用软件包”，分析及仿真工程师Peter Kelm说。

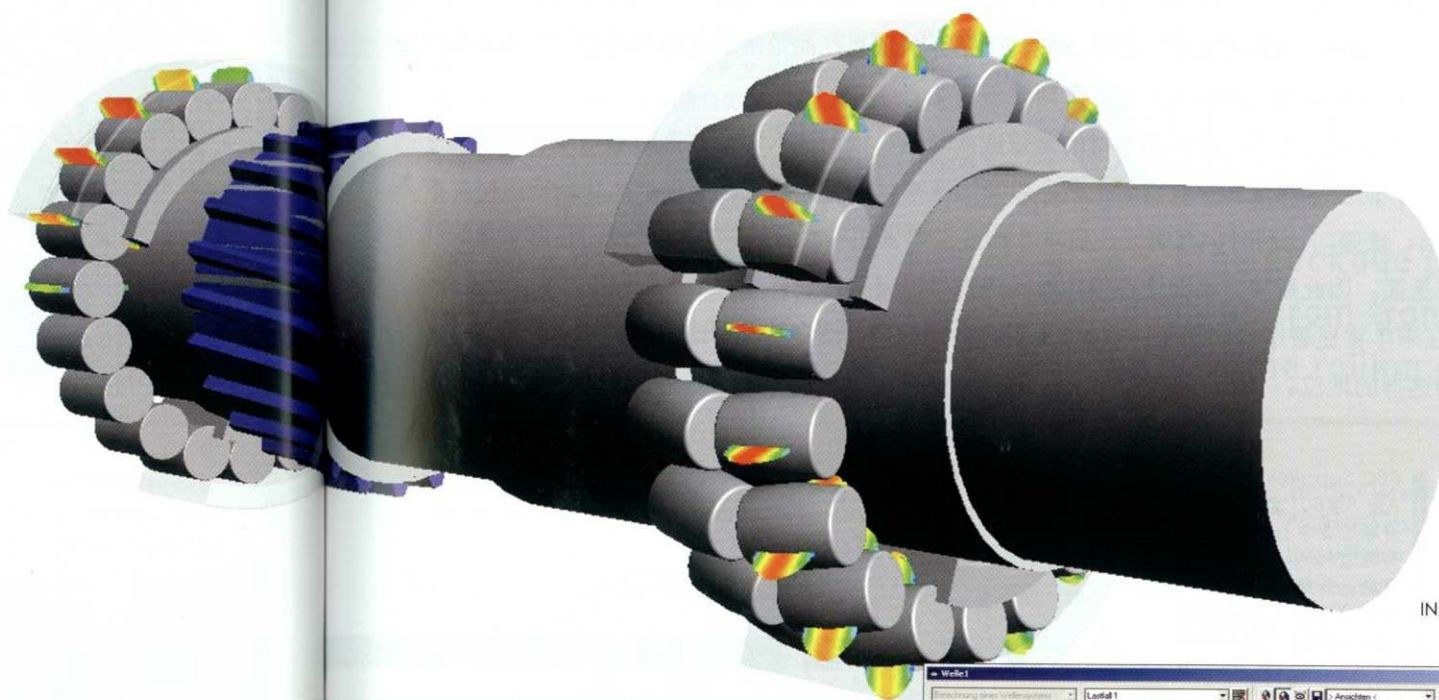
“它们帮助我们达到了汽车制造商提出的总体成本降低，研发周期缩短的要求。”

INA公司的目标是开发特殊用途的应用软件包，而不是那些有着更广泛用途的工具。这一策略可以让INA公司的应用工程师进行仿真

The right software is essential in order to take the guesswork out of product development. It is particularly true in the drivetrain where the frictional forces are the most complex and critical. Developing prototype transmissions is expensive and time-consuming, but any warranty issues once production starts can be far more costly.

To be a successful supplier these days you have to do a lot of work with the traditional standard analysis packages available. But to gain a commercial edge, many now develop their own software to understand their products more completely and to provide better support to their customers.

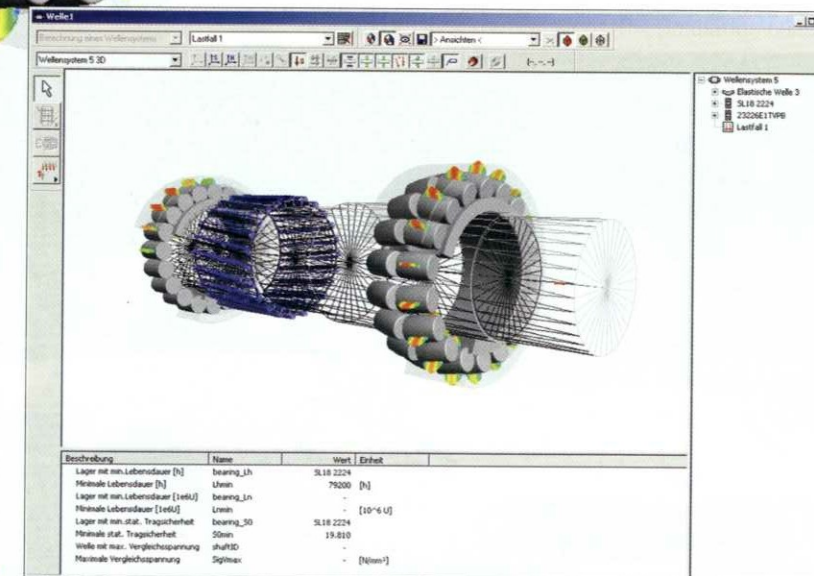
INA-Schaeffler of Germany has been taking this approach for some time. The company, a specialist supplier of rolling bearings and components for engine applications, uses a number of in-house packages to improve the development process. “We developed Bearinx, Simpl and CABA in-house because there was nothing on the market that satisfied our needs,” says analysis and simulation engineer Peter Kelm.



轴分析的Bearinx屏幕截图  
INA's Bearinx programme analyses pressure distribution in shaft

感觉以便消费者量化他们希望达到的档位感觉

Suppliers develop their own software to understand their products better and to gain a commercial edge



进而加深他们对系统的了解，这项工作在其他公司是安排给资深专家做的。

滚动轴承是INA公司的骨干业务，耐用性是一个关键的问题。计算轴承在一个变速器中的工作负荷是非常耗时的。通常你需要对整个变速器进行计算。即使专家使用现代化的软件，这一过程也可能持续两星期之久。“所有的变速器，不论它在世界上什么地方设计的，都通过我们的办公室（测试）”Kelm. 说道：“计算大约100个变速器需要很大的资源和知识水平，我们希望克服这一瓶颈”

该公司运用他们的Bearinx软件包仿真并分析变速器。仿真过程开始前需要几个小时来设置，然后只需要几分钟的运行时间就能够得出结果。该软件包早在设计过程中就得以应用以保证成品能够满

“They help us reach the overall cost-reduction and the shorter development cycles demanded by car makers.”

INA targets its development towards very specific applications, rather than creating tools for broad use. This enables INA application engineers to perform simulations - and thereby increase their system understanding - that would be assigned to specialists otherwise.

In rolling bearings, the mainstay of INA's business, durability is a key question. Calculating the bearing loads for a transmission, however, can be very time-consuming. Ordinarily you would have to do a calculation for the entire transmission.



理论上,所有物品都是可以连接起来的。

具有全球个体解决方案的重要设计研发伙伴,就是扣件专家——安贝格市Kerb-Konus。

……无论从那点看,许多材料都有安全方面的极限。目前,热塑和热固材料、钢铁和有色金属提供了多种选择:来自Kerb-Konus的机械连接部件经受住了全世界无数塑料应用、金属加工和材料结构的考验。

作为具有50多年实践经验的制造商,Kerb-Konus与客户紧密协作协调,不断开发并提供扣件解决方案。技术指导Frankbert Klarner解释说:“在个案中,方案可能是一项特殊设计,甚至是现有产品范围的修改和综合。”公司的广泛计划满足了汽车制造商、机床和设备制造商以及电子工业的苛刻要求。

在产品的搭配组合中,客户们可以看到:金属、塑料和木材的螺纹嵌入螺帽,模制嵌入螺帽,铆钉螺帽以及薄壁模子的螺纹插脚,薄壁模子的冲压铆钉,防脱落螺丝和螺纹密封工艺,以及隔离螺纹密封的涂层。所有产品都在安贝格生产。

Kerb-Konus在瑞士、英国、法国、比利时、西班牙、日本、印度及美国也有生产厂。而且,公司在所有重要工业国家里的商业伙伴扩展了其覆盖面。因此解决方案即使在很短时间内也可以得到保证。

2003年约4000万欧元的收入在来年将显著增长。Dirk Uelze博士说,他们公司的使命就是“成为所有当前全世界零件市场上的主要竞争者之一并保持这样的地位。”

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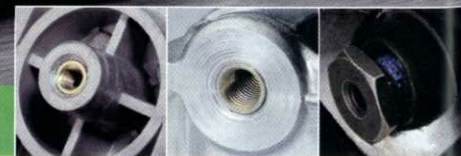
可靠的控制技术



……当顶尖的演绎成为标准

对技术设计工程师来说,在汽车设计和其他工业领域中,用经济有效的方法把不同金属和塑料连接起来是最为苛刻的挑战。今天,最高性能就是您的标准。进一步的自身创新与研发确保您的企业在明日市场上取得成功。

企业的市场,制造商与供应商之间的创新合作举足轻重。KerbKonus是紧固技术市场上的领导者之一,拥有KerbKonus的产品,你就可以万无一失。不管是目前应用,还是未来导向新发展。全球范围



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足用户的特殊需求。当用户使用新的零件或附加系统对现有的变速箱进行升级的时候,变速箱会产生意想不到的问题,例如噪音、震动,异常磨损。INA为他们进行仿真以发现哪些地方需要改进。

软件包提供集成的对于从变速器水平到滚动元件接触,甚至包括对柔性零件进行深度分析的功能。就象一根连杆在动态负荷下会变形一样,同样的情况也会在变速器的行星传动器上发生。“初始的目的是了解在轴承水平的情况,这样我们可以采取相应措施以预测并防止故障”Kelm说。研发时间缩短和费用降低是经常获得的结果。

许多年来,INA公司使用他们的2维建模软件Simpl进行动力学仿真以作为Bearinx软件包的补充。作为一个2维模型,在建模能力上显然有许多局限,

虽然如此,但它还是非常具有实用价值的,例如应用在对行星齿

Bearinx软件包仿真并分析变速器  
Bearinx package simulates and analyses transmissions

## 软件包提供对于从变速器水平到滚动元件接触深度分析的功能

The package provides in-depth analysis from transmission level to the rolling element contact

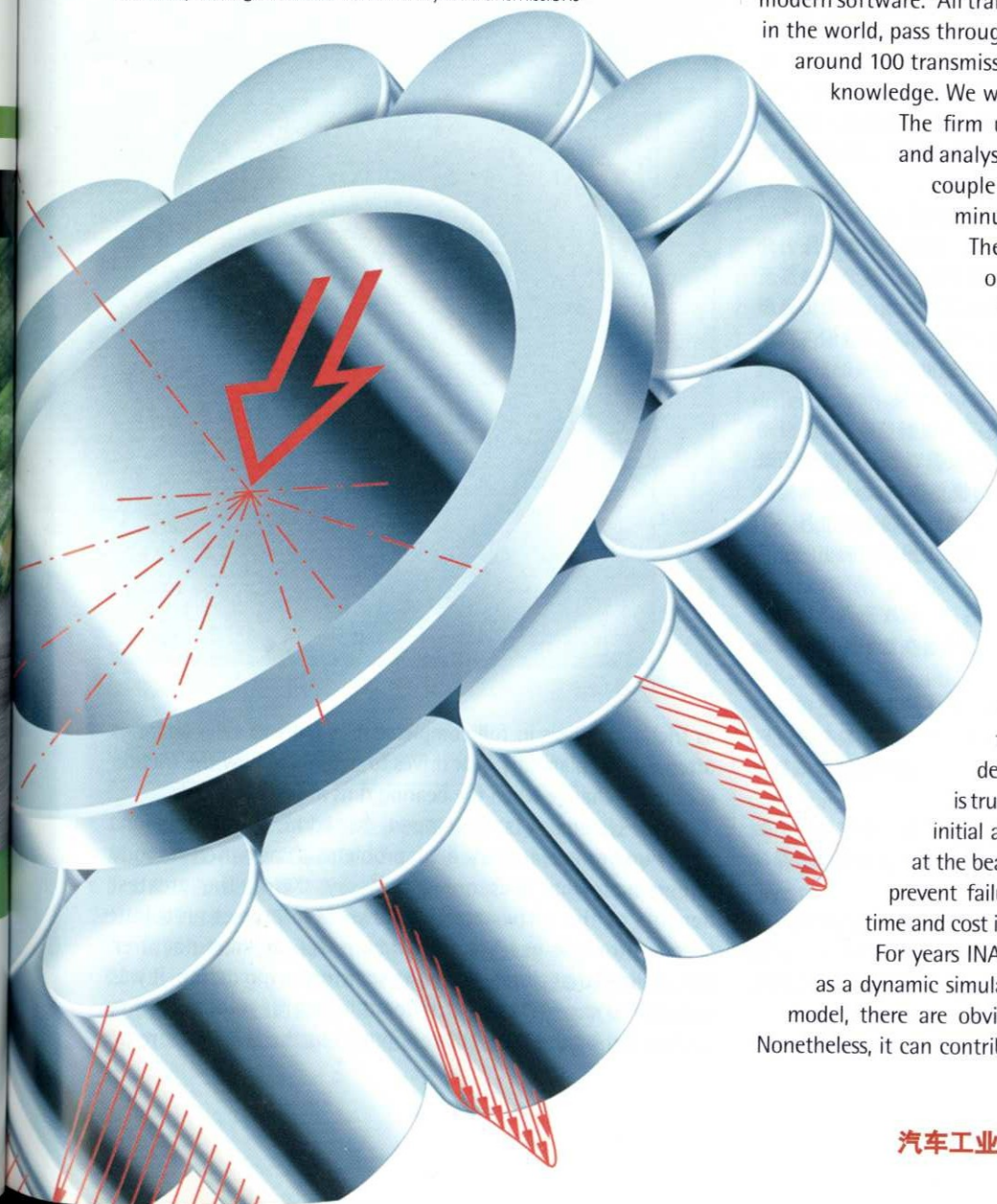
This can take up to two weeks, even with specialists using modern software. “All transmissions, wherever they are designed in the world, pass through our offices,” says Kelm. “Calculating around 100 transmissions a year takes a lot of capacity and knowledge. We wanted to overcome this.”

The firm uses its Bearinx package to simulate and analyse transmissions. The simulation takes a couple of hours to set up. It is then a couple of minutes before it starts to produce results.

The package is run on applications early on in the design process to ensure the finished product will meet customers' specifications. When customers update an existing engine or gearbox with new components and add-on systems, they can suddenly develop unexpected behaviour like noise, vibrations or premature wear. INA runs the simulation for them to find out what must be changed.

The package provides an integrated in-depth analysis from transmission level to the rolling element contact and even includes flexible parts. Just as a connecting rod deforms under dynamic loading, the same is true of a transmission's planetary drive. “The initial aim is to understand what is happening at the bearing level, then we work to predict and prevent failure,” says Kelm. Reduced development time and cost is often the upshot.

For years INA used its 2D modeling software Simpl as a dynamic simulation complement to Bearinx. As a 2D model, there are obvious limits to its modeling capability. Nonetheless, it can contribute significantly to applications, such





## INA公司的手动变速箱档位模拟器使说出哪些参数需要调整更容易，并能观察到不同的部件使用后会发生什么情况

轮传动器经常需要进行的，以确定摩擦状态是如何随着轴承运行在不同的特定转速下而改变的满装圆柱滚子轴承总成摩擦分析中。

开发该系统以解决变速器受到的行星齿轮问题的困扰。“在此之前没有人知道将会怎样”Kelm说，该软件的巨大效益在应用于一个为欧洲汽车制造商生产的四速自动挡变速器项目时展现得淋漓尽致。INA公司仅仅通过简单地改变了轴承设计便感觉到了这一点，这样做的结果是减少了1.7kW的摩擦带来的动力损耗。他接着说：“这相当于变速器内去掉了个加热系统，降低了20°C的温度。这也可以用使用传统润滑油与使用合成润滑油的差距来形容，因此对于费用的节省是惊人的。”

CABA, INA的软件包最新的进展是变得更加完善了，可以用来研究任何种类轴承的动态特性，而且是3维的。负荷，扭矩，压力分布，应力水平和滑动分布可以被分析并且显示出来。这个程序甚至可以在部件还未制造测试之前，预测部件的工作状况。“它仿真事物，其它的（程序）恰恰做不到这点。这个特点拉近了我们与客户的距离。我们可以被集成到制造商的计算机辅助工程（CAE）过程中，并在产品研发的虚拟阶段完成许多工作”Kelm说。

INA公司使用虚拟实验台来为一家美国大型制造商的6速自动变速器进行优化。该程序使INA的工程师可以看到当负荷及型面改变时发生的情况。这使他们可以向生产商提出改进设计的意见以减少摩擦降低温度。“CABA使该项目的研发周期缩短了一个月。”Kelm说。“虽然需要数月来搭建实验台，但它仅用以天和小时计算的时间来验证事物。”

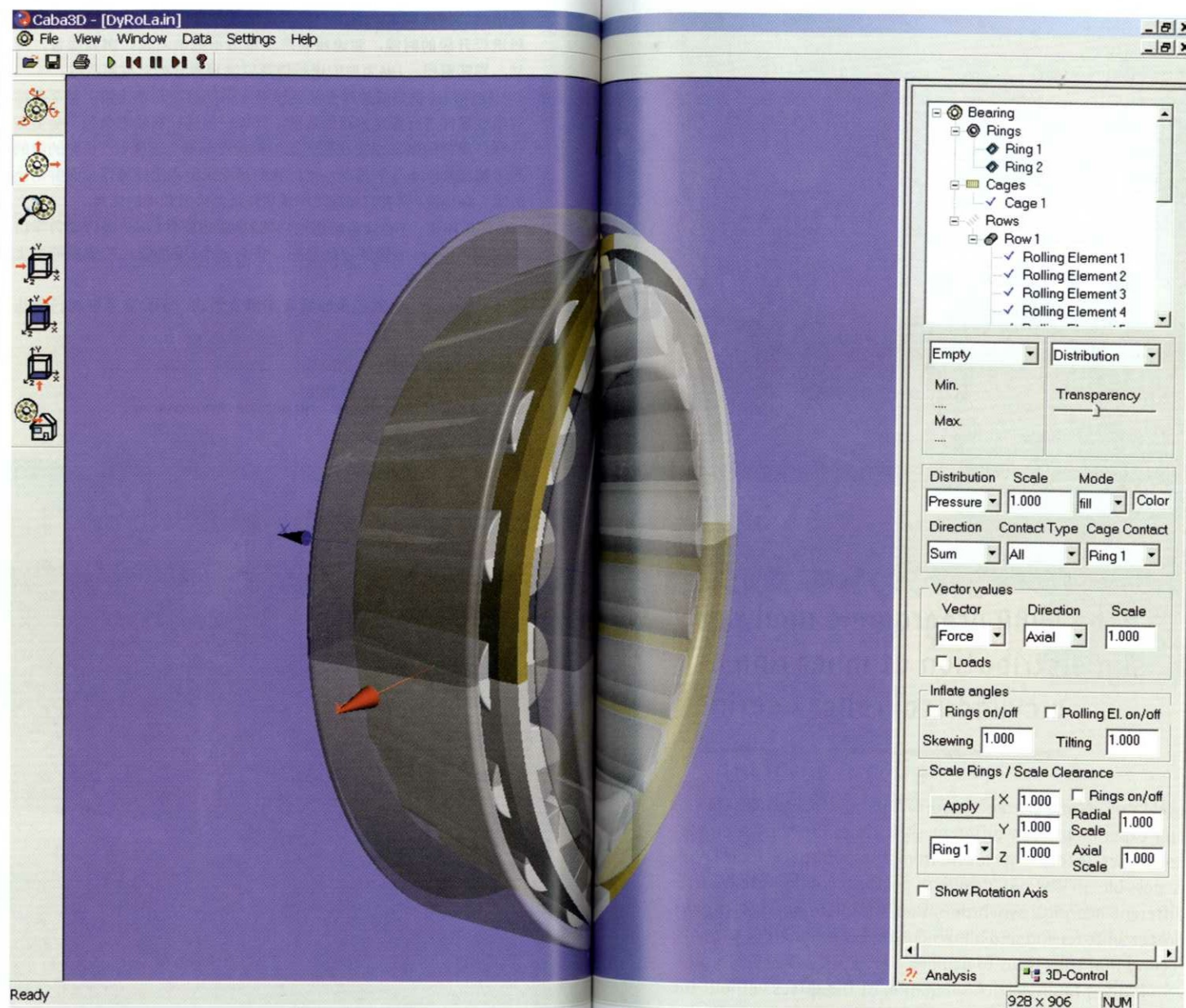
对于手动变速器，INA使用不同的分析方法。效率更高，特别专注于使换挡更舒适准确。制造商必须保证驾驶者在空档的时候明确知道，并选择正确的档位。

驾驶者必须清晰地知道变速器是好用还是不好用，难点在于如何量化消费者的需求。车辆的不同型号使这项任务更加复杂了：以保时捷（Porsche）车的变速器为例，其设计和一辆紧凑型轿车有非常大的差别。

同步器调整档位，当驾驶者从一个档位换到另一个档位时，轴的速度不一致。换挡时轴和齿轮速度要相同，不然变速器就会受到损伤。支承结构为变速器承受压力起到重要作用。

定位销对档位感觉也起到重要作用，它沿着一个曲面移动，以决定工作和非工作齿轮的位置。“我们优化了曲面的周线和定位销内部圆形屋顶顶的廓线。为了产生正确的感觉，我们计算了在换挡过程中的摩擦扭矩及阻力”Kelm说。

计算开口的周线是一个公差问题。每一个部件都有不同的公



CABA程序分析圆锥滚子轴承  
CABA programme analyses a tapered roller bearing

as friction analysis in full complement cylindrical roller bearings often used in planetary gear drives to determine how the friction conditions change when the bearing runs at certain speeds.

The system was developed to address transmissions suffering from planetary gear problems. “Back then nobody understood what was going on,” says Kelm. The greatest benefits of the software were shown by a project on a four speed automatic gearbox from a European car manufacturer. INA realised that simply by changing the bearing design, it was possible to save 1.7kW in frictional losses. “It took a heating system out of the transmission, reducing the temperature by

差。如果开口太紧，换挡就会非常困难，开口太宽则档位就没了导向。找到折中的方案是关键。“你接下来需要找到最适合的公差和什么是制造过程中最需要重视的。”Kelm说。可以将可忽视的公差分离处理这样就能得到一个经济的解决方案。

软件作业只是INA公司推出的换挡过程仿真的一部分。该公司还研制出一种真实大小的换挡模拟器。制造商可以座在模拟驾驶室中亲身体会不同档位的感觉。该换挡模拟器利用了源自航天工业的技术。它可以让体验者尝试不同的变速箱配置不同的轴承，同步器，

around 20°C. It can also mean the difference between having to use conventional lubricants and synthetics, so there is some impact on cost,” he says.

CABA, INA’s most recent addition is more sophisticated, able to study the dynamic behaviour of any kind of bearing – in 3D. Loads, torques, pressure distribution, stress levels and the distribution of slip can be analysed and displayed. The programme can predict how components will behave even before the part is made and tested. “It simulates things, which others simply can not. This helps us to be close to our customers. We can integrate into manufacturers’ CAE processes and do a lot at the virtual stage of product development,” says Kelm.

INA used the virtual test-rig to optimise a recent six speed automatic for a big US manufacturer. The programme let INA’s engineers see what happens when loads and profiles were altered. It enabled them to suggest changes to the design to reduce friction and heat. “CABA saved a month in the development cycle of the project,” says Kelm. “While it would have taken months to build a test rig, it proved things in a matter of days and hours.”

In manual transmissions, INA does a different kind of analysis. Efficiencies are better and the focus on getting the shift comfort right. Manufacturers must make sure the driver knows when they are in neutral and are selecting the right gear.

Drivers have a clear idea of whether a gearbox is good or bad. The hard part is quantifying what the customer wants. The type of vehicle also makes the task more complicated: the transmission in a Porsche, for example will be designed very differently to the gearbox for a compact car.

Synchronisation adjusts the speed in the shift. As the driver shifts from one gear to another, the speeds of the shafts differ. They must be equalized or they damage the gears. The supporting structure plays an important part in how the transmission copes with the stresses.

The detent pin also plays an important part in determining shift feel. It rides along a curved surface, which provides the engaged and disengaged positions for the different gears. “We optimize the curved contour and the design of the dome-like profile inside the detent pin. To give the right feel we calculate the friction torque and the resistance during shifting,” says Kelm.

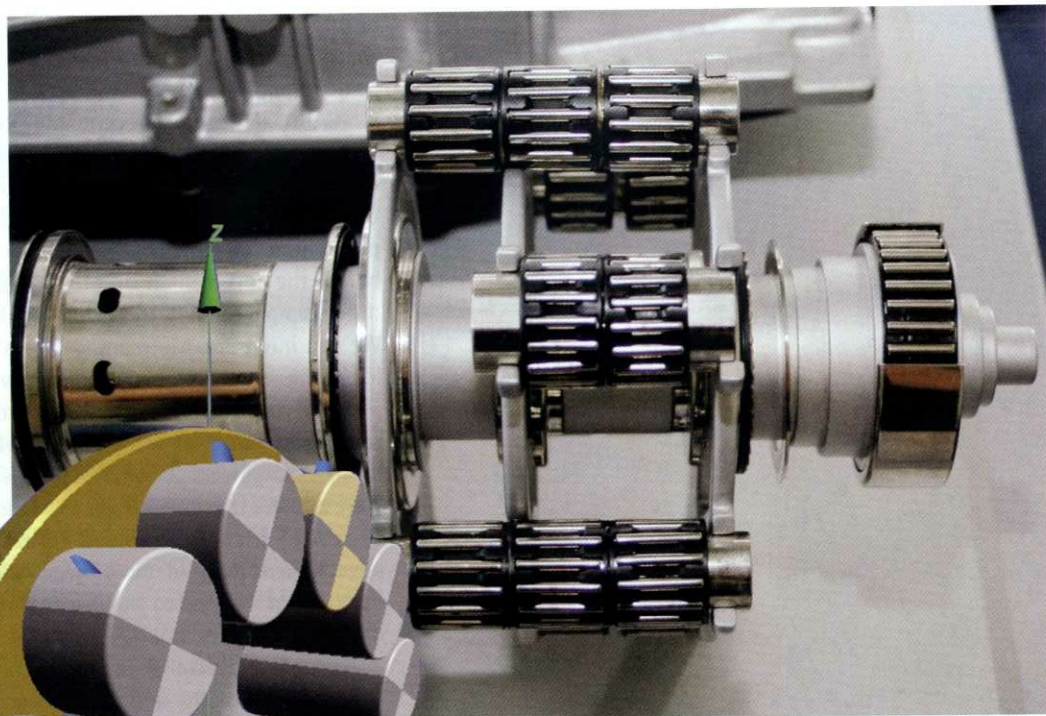
Designing the gate’s contours properly is a tolerance issue. Each part carries a different tolerance. If the gates are too tight, shifting becomes too difficult; too wide and there’s no guidance. Finding the right compromise is essential. “You then have to find out what tolerance has the most impact and what is important for manufacturing,” says Kelm. “You separate the tolerances that aren’t important so you can come up with an economical solution.”

The software work is just one part of the shifting simulation INA carries out. The company has developed a life-size shift



## CABA程序 分析圆柱 滚子轴承 内圈滑动 分布

CABA分析圆柱滚子轴承的压力分布  
CABA analyses pressure distribution of a cylindrical roller bearing



### The CABA programme analyses slip distribution at inner ring of a cylindrical roller bearing

simulator. Manufacturers can sit in a mocked-up cockpit and experiment with different shift feels. The shift simulator itself uses technology taken from the aerospace industry. It is possible to try out different gearbox configurations with different bearings, synchronisation and plate designs. It gives proper shift feeling and allows customers to quantify the shift feeling that they want to achieve.

"It gives full feedback simulation of the forces without the need for a real product," says Helmut Adler, vice president of strategic marketing. "We can use different numbers of aisles and gate contours. The friction forces are included in the model." It makes it a lot easier to say what parameters need tuning and to see what happens when different components are used.

Reducing time and development costs is a major aim. "Previously there were a lot of cycles between the manufacturer and the supplier, costing a lot of time and money. Anything between five and 15 iterations was possible. The simulator is helping reduce the time," says Adler. "Building a relationship and trust takes time. This is a good way of communicating to customers what you want to do and why." ■

和盘设计的区别。它给出了恰当的档位感觉以便消费者量化他们希望达到的档位感觉。

“他给出了可以在不需要实际产品的情况下得到关于力仿真的全面反馈信息的解决之道。”营销战略部的副总裁Helmut Adler表示。“我们可以使用不同数目的通道和开口周线，摩擦力已经包含在模型里。”它使得更容易说出哪些参数需要调整，更容易观察到不同的部件使用后会发生什么情况。

减少研发时间和费用是主要目标，以前在供应商和制造商之间存在许多环节，消耗了许多时间和金钱。任何事重复5到十五次都是可能的。模拟器帮助减少所需时间” Adler说。“建立关系和信任也需要时间，这是一种让客户了解你想做什么，为何做沟通的好方法。”