Parallel Kinematics: Ready for Mass Production

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It’s not easy for new technologies. First there is a great deal of enthusiasm: engineers are involved from the very beginning, look forward to good sales and somehow hope to eliminate problems, most of which they’ve already thought about. After this though, a stagnation phase sets in.

This was probably no different in the case of parallel kinematics machines (PKMs). The idea was promising, and designers got ready to quickly sift through 100 years of conventional machine-tool history. The first prototypes were completed as early as 1997 and exhibited at the EMO trade show. Just two years later, 16 different exhibits from this area were displayed, and an article submitted by INA about a product line specially developed for PKM appeared in the special EMO issue of the German trade magazine Werkstatt und Betrieb. What was missing though was the “real” mass-produced machines – machine tools with big benefits for end customers and in high volumes that make PKMs more interesting from an economic standpoint.

That will all change at this year’s EMO, because the first production-ready machine tools will be on exhibit.

Big – Strong – Fast

EADS, previously known as DASA, is one of the precursors in PKM implementation. In March 2000, “Ecospeed”, the first Tripod, manufactured by DS-Technologie, was put into operation at the EADS plant in Augsburg. EADS requirements with regard to dynamics, 5-axis machining with spindle pivot angles up to +/-40° as well as a significant increase in total productivity reached their limits using conventional designs. DS-Technologie’s solution was a tripod that is used as a modular component of a complete manufacturing cell and combined with conventional technology. A special effort is made to utilize the advantages of PKM technology and, at the same time, work around disadvantages inherent to the design.

The tripod concept is based on a design incorporating constant-length “struts” and driven “end points” that are traversed using conventional technology, i.e. ball screw drives. In the selection of PKM components such as joints and pivot joint bearings, INA is DS-Technologie’s engineering partner. For instance, U-joints with a stiffness of 500 N/mm play a decisive role for the design of the work platform. The joints used are special solutions for DS-Technologie that are based on standard component designs.
A common view about PKMs holds that only tension and compression forces are transmitted, but bending stresses are also present in the rod end for this kind of tripod kinematics. The U-joints were optimized accordingly to handle these stresses. DS-Technologie also relies on INA’s precision components for conventional feed axes such as guides and ball screw support bearings.

The result was that the new design allowed a significant increase in performance to be achieved. The tripod allows feed speeds of up to 50 m/min. and accelerations up to 1 g in the linear axes. Up to 7,000 cm³ of aluminum can be cut per minute, which corresponds to approx. 20 kg of aluminum. At the same time, manufacturing times are reduced by 30–50%. [1]

As mentioned above, the “Ecospeed” is a type of hybrid kinematics. The tripod module is not the only component responsible for motion along the axes in space. To reach a larger work area, i.e. for milling frames, the tripod head is added to two conventional axes. Because of this arrangement, the tripod can be moved toward the machining area. This configuration represents a significant improvement on the ratio of machine size with respect to work area, which is often unfavorable in the case of pure PKMs. The machining head used by DS-Technologie also fills the gap found with conventional machines for this application. Ecospeed ensures reliable manufacturing for honeycomb structures with wall thicknesses less than one millimeter.

Blazing New Trails
Who is not familiar with the dynamic work centers supplied by Heckert Werkzeugmaschinen, especially the CWK 400D, which is regarded as one of the fastest in its class? And now they want to take this one step further: the “end of mass movement” has been announced for the SKM 400 tripod. The goal is to achieve similar accuracy and more dynamics for the same machining space, all at significantly reduced costs.

The concept is a tripod with axis modules spaced 120° apart as well as a double coupling link. A rotary table was added for 5-axis machining, making the machine very flexible for the applications involved. Regardless whether 5-axis machining is to be used for mold making, pallet changing or to be included in a manufacturing line as a 3-axis machine, the SKM 400 is equipped to do the job. [2]

Heckert blazed new trails with INA in working out a concept for the drive. Neither the almost classic telescopic struts nor the constant-length struts with linear modules were used, but rather axis modules with driven nut & bearing support and direct drive. The idea was to place the entire weight of the powertrain about the pivoting axis of the cardan suspension. The inertial torque around the suspension axis is greatly minimized for this configuration, which allows high jerk values without disturbing transverse vibration. This is also promoted by the high natural frequency of the ball screw, which has a significantly larger diameter than telescopic struts for instance due to the driven nut and bearing support. In contrast to many PKM prototypes, the SKM 400 can thus exhaust all potential in terms of dynamics and can reach maximum acceleration values very quickly. In addition, the ball screw and the motor are cooled to minimize thermal effects.

An important aspect here is that INA supplied Heckert a complete system for the SKM 400, i.e. no time and effort are required for mounting drives, measuring systems, etc. The design also means that the time-consuming work needed to prepare guide raceways and to align guides is eliminated. This allows mounting times for machines used in volume production to be decreased significantly. An approximate cost savings of 10 % is planned for the long term. [2]
There are currently several users who are interested in a pilot version of this machine, and they intend to use the SKM 400. In the start-up phase, volumes are of course still low, which is not easy for the supplier cost-wise. On the other hand, the idea of being accepted as a system supplier is very important to INA.

Precision Tops the List
The topic of accuracy plays a key role in current PKM developments. With regard to speeds for rapid motion, acceleration and jerk, there are already quite a few things that speak for PKMs. The critics though like to compare the accuracy of a PKM with that of conventional machining centers.

One important factor for PKM accuracy is calibration, in other words the adjustment of the mathematical model to the machine geometry. Just as important are the influencing factors in operation that change machine geometry. Such factors here include thermal effects, deformations, vibration, etc. Finally, accuracy will also depend on whether a tripod or a hexapod is used. In general, for hexapods, machine manufacturing accuracy does not represent an influencing factor with respect to the machining accuracy to be achieved. The only thing that is decisive here is the determination of the actual geometry by means of calibration. In the case of tripods, however, machine manufacturing accuracy plays a decisive role due to the different system.

The topic of calibration is also an important issue in the “Innovative Machine-Tool with Parallel Kinematics” project, which is sponsored by the Baden-Württemberg Ministry of Trade and Commerce and includes participants from the machine-tool and supplier industry.

For the first time, the calibration procedure developed at the Zentrum für Fertigungstechnik Stuttgart (ZFS = Stuttgart Manufacturing Technology Center) allows a decisive increase in hexapod accuracy by calibration only. What must be emphasized here is that this accuracy refers to a real-life work area. Researchers have been able to reach the defined accuracy target of less...
than 10 µm on a 300-mm circle and demonstrate that in terms of accuracy and calibration, this kind of kinematics is suitable for practical applications. [3]

The best way to record the effects of disturbing factors such as deformation and temperature would be to perform a direct measurement on the tool center point (TCP). However, there is still no measuring system or measuring strategy for this application. As a manufacturer of precision components, INA decided to develop an integrated measuring system for telescopic struts that can be used to determine the distance between the swiveling axes between the frame and the platform during operation. In this way, geometric changes due to thermal effects and deformations can be obtained, which leads to a significant increase in accuracy. In principle, this idea is not new. Measuring via the strut axis was implemented for some prototypes, e.g. via laser measurement. However, INA wanted to find a practical solution using conventional length-measurement systems. Initial studies performed in cooperation with Heidenhain will be introduced at the 2001 EMO trade show. Together with the RWTH-Aachen (Aachen Polytechnic), a trial run will be held within the scope of the European Union’s Mach 21 project with the aim to market a mass-produced product by the beginning of 2002.

Future Prospects
Besides the Heckert SKM 400D and DS-Technologie’s Ecospeed, there are surely other machine designs (e.g. the Index V100) that look promising. Many design studies such as the mobile repair unit developed at the University of Hanover, have potential for industrial application. These examples demonstrate that there is a turn away from the research object and that more emphasis is being placed on the product. Mainly key industrial customers and automobile manufacturers see benefits in this technology.

INA will be involved in the development of other PKMs ready for mass production, and these will be on exhibit at the 2001 EMO trade show. New components for these applications will also be presented. The trend is definitely heading toward hybrid kinematics – be it tripod configurations or plane PKMs – in conjunction with conventional axes. In my view, this will have a positive influence on the relationship between machine volume and the work area, which is certainly an important aspect for mass-production users. This concept is obviously more acceptable for customers than the still rather “exotic” hexapod. It’s this customer acceptance that will be decisive for further developments and above all allow parallel kinematics to spread.

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