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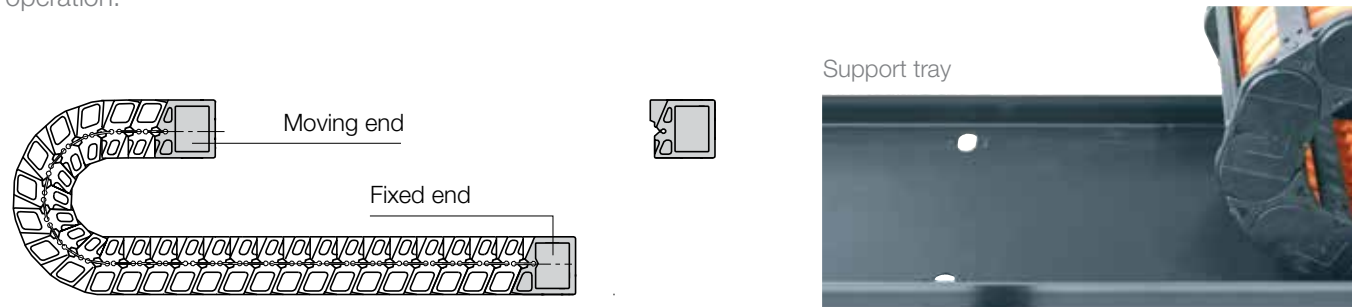
Influence of vibration on machine tools

Vibration behavior of e-chain systems®

iglus®

The problem

The requirements for precision of machine tools are constantly growing. Their increasing automation gives specific challenges; for example, the influence of the vibration of machine components on the finished workpiece is an important factor when cutting and milling. e-chain® cable carriers, the "umbilical cord" of the modern machine tool, are a possible source of vibration that can cause problems. As the technology usage increases, the use of cables and hoses guided by e-chain® cable carriers also grows. During the necessary operational movements, vibration occurs in the trough and at the moving end and can adversely affect the result and the entire production process if they exceed a certain tolerance band. In international competition, the German machine tool industry especially depends on premium products whose productivity and accuracy differentiate them from competitors' products. Factors that limit the performance of machine tools must be overcome with innovative technologies. Suppliers of quality machines used in tool manufacturing are therefore dependent on energy supply products that offer minimal vibration and extremely smooth operation.



Cross section and front view of an e-chain® cable carrier with key vibration points, namely the moving end and the trough
(Source: igus® GmbH).

Cutting and milling precision

Dynamic loads always generate types of vibration that can cause displacement of the tool and the workpiece during machining, which impairs metal cutting. Increasing deterioration of the cutting conditions of metal-cutting machine tools can lead to process instability. So-called chatter vibration occurs which leads to loss of quality in the machining result and increased wear of machine components. Product defects and production downtimes are the consequence. As the materials that are used are increasingly difficult to machine and, at the same time, the market demands better machining performance for the same size of machine, the use of low vibration machine components is more important than ever. Smoothly operating e-chain® cable carriers are therefore indispensable for the limitation of self-generated machine vibration.

State of the art

Most e-chain® cable carriers that are currently being used have a pin/bore connection system. This standard feature guarantees that the chain links are securely connected to each other in dynamic applications. Due to the nature of this connection, the energy supply systems are robustly protected against bending stress, while demonstrating a high degree of tensile strength and mechanical load-bearing capacity. However, manufacturers still have to reckon with the so-called "polygon effect". While moving through the bend segment, the chain performs a turn that is not completely round. Unwinding of the links occurs. A circle, which is the ideal movement for the chain, becomes a polygon. This leads to longitudinal and lateral shocks that can cause vibration. However, improving the vibration behavior of e-chain® cable carriers is the aim of every manufacturer. Different approaches to a solution for this problem are taken. Most makers of quality chains mainly rely on a small pitch of the links for low noise and smooth operation.

Characteristics of the igus® e-chain® technology.

All igus® chains are very robust, low vibration products and are therefore ideal for applications in machine tools. In the case of the e-chain® cable carriers with a pin/bore connection system, igus® also adopts the small pitch approach as a design principle for smooth, low-noise operation. For especially challenging applications where a maximum reduction of vibrations is the goal, igus® has also designed an innovative connecting component for the links: an elastic spring element made of high-performance plastic. Instead of the conventional, relatively rigid connection consisting of pin and bore, the E3, E6 and E6.1 series of e-chain® cable carrier feature flexible connectivity, which reduces the polygon effect to a minimum when the chain rolls. In this way, extremely low noise and almost vibration-free operation of the chain are possible. Very smooth, low noise operation and simultaneously high rates of acceleration can be achieved with the E6 e-chain® cable carriers. In 220 million test cycles in the igus® technical center, the design innovation was able to demonstrate its advantages and effectiveness. In a long-term test in 2008 with the E6.29 e-chain® cable carrier, the spring element underwent more than 400 million complete bending movements. As an independent assessment by the Fachhochschule (technical college) in Cologne showed, none of the fasteners used showed any visible or measurable damage.



The spring element also fits in with the modular approach to the e-chain® cable carrier structure. The links on the sides of the chains can be quickly attached or detached by inserting or removing the springs, the result being that the energy supply system can very easily be adapted to the individual requirements of the respective application, then filled with cables and assembled. The chain is openable along the inner and outer radius. A plastic hammer and a screwdriver are all that is needed to easily and quickly push the fasteners in or out by hand. The fact that interior separation can be organized in a variety of different ways through the use of separators and dividers on the one hand, and different width shelves on the other, allows a specifically defined layout and fast cable filling.

Elastic spring elements as vibration-dampening fasteners for chain links (source: igus® GmbH).

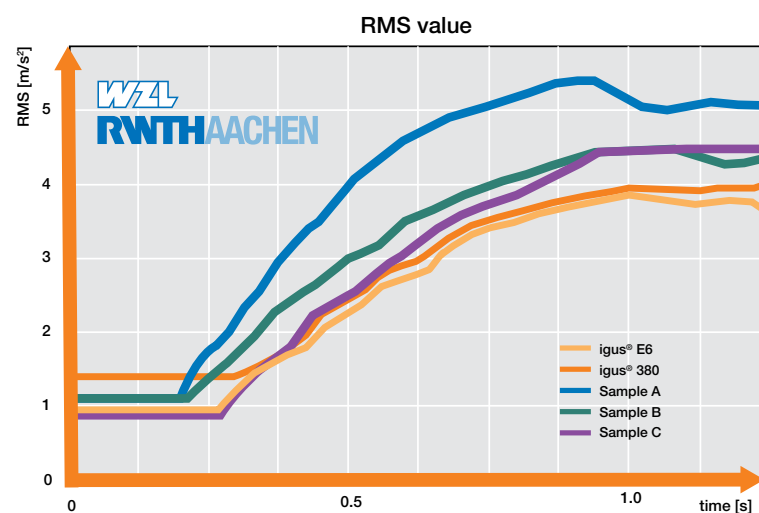
According to tests of the IP Fraunhofer Institute, the corrosion-resistant polymer material of the chain and springs is characterized by excellent abrasion resistance and low wear, whereby the chains and springs made with special material comply with the highest quality standard for cleanrooms (ISO Class 1). The smoothness of operation is expressed in the low amount of noise that the E6 generates; the measured sound pressure level of only 37 dB(A) is well below the levels of competing products, a fact which an assessment of TÜV Rheinland (Technical Inspectorate Rhineland) confirms. The chain becomes more elastic without any loss of tensile strength. Even highly dynamic applications with millions of reverse bends are possible, without the occurrence of any faults or abrasion. All this is a guarantee of a very long service life. When used in combination with a linear motor whose drive is also designed for low vibration operation, the vibration behavior is reduced to a minimum, which is beneficial for the workpiece when finally produced.

Case study of "vibration behavior": A scientific comparison of e-chain® cable carriers

A study carried out by the Laboratorium für Werkzeugmaschinen und Betriebslehre (WZL) of the RWTH Aachen was dedicated to a comparison of the vibration behavior of five different e-chain® cable carriers. The two E6 e-chain® cable carriers from igus® and three comparable e-chain® cable carriers of other suppliers were examined. With inner widths of 100 to 105 mm and inner heights of 42 to 52 mm, all the chains were of the same size category. The test rig consisted of a base frame and a highly dynamic direct drive, which moved the carriages driven by a linear motor (feed force 14,000 N)

at four speeds (25 m/min, 50 m/min, 100 m/min, 200 m/min) and at two rates of acceleration (10 m/s², 20 m/s²) over a travel of 800 mm. The magnitude of the vibration was measured by means of acceleration sensors with a sampling frequency of 6,000 Hz that were fitted to the trough of the e-chain® cable carriers in each case. The data relating to the forward movement of the carriage were measured separately from the data for the reverse movement in order to avoid any mix-up of measured values due to the two directions of movement. The signals detected by the sensors were evaluated in the time range and the frequency range. In the time range, the RMS value is a measurement of the vibration energy at the measuring point. The RMS (Root Mean Square) value of the vibration energy at the measurement point was the lowest for the two igus® e-chain® cable carriers (source: RWTH Aachen).

In the case of all e-chain® cable carriers, the greatest vibration energy was at the trough in the direction of the Z axis. The comparison test accordingly concentrated on these maximum vibration signals in the Z direction. The different acceleration rates of 10 m/s² and 20 m/s² had no significant influence on the vibration values of the e-chain® cable carriers. The results show that, compared to the other e-chain® cable carriers, the E6 e-chain® cable carrier has the best



(Source: WZL RWTH Aachen)

properties in regards to vibration behavior and smooth operation. This result applies to low and high speeds. On average, the measured vibration was 28 per cent lower than that of the other e-chain® cable carriers. The E6 type of chain had the maximum RMS value of approx. 4 m/s². The RMS value of the cable carrier with the most vibrations was even 40 per cent worse at 5.6 m/s². At the moment, the E6 e-chain® cable carrier is the e-chain system® solution with the lowest levels of noise and vibration.



E6.1: The new generation of low noise, smoothly operating e-chain® cable carriers with inner heights up to 80 mm (source: igus® GmbH).

Summary

The growing requirements regarding the precision of machine tools call for technical innovations in the area of vibration reduction. Achieving smoother operation of e-chain systems® in dynamic applications is an important component of a successful strategy. The avoidance of vibration by using machine components that have been optimized for low vibration is the most cost-effective way of doing this. New solutions such as the elastic spring element as a fastener for the links of e-chain® cable carriers make a decisive contribution towards achievement of the goal of "low vibration machine tools".

Leadership of the market due to continuous product research and proximity to the customer

With its comprehensive range of 90,000 e-chain® products, igus® has acquired technical market leadership in this special area of energy supply. The company has almost 50 years of practical experience with e-chain® cable carriers. The first chain was delivered as early as 1971. In order to maintain its position, igus® relies on its permanent research and development activities. This is why it operates the industry's largest test laboratory. In an area of more than 2,750 m², 30 employees carry out 4,100 tests per year on 65 test machines in the e-chain® laboratory alone. Technical innovations such as the elastic spring element are subjected to a test marathon consisting of tests under realistic conditions, whereby behavior in respect of tensile forces, thrust forces, coefficients of friction, abrasion, external influences and vibration is examined. The more than 7,500 test results obtained are recorded in an electronic database and are used for continuous product improvement. They are also available to the customer by means of online tools. The reason for this is that research and production at igus® are always customer-centered. Open cooperation guarantees the best possible result for both sides. With this in mind, igus® also cooperates with customers when it comes to design and assembly and, acting according to the slogan "igus® the-chain", tries to find the most suitable system solution with and for each customer.

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The terms "igus", "chainflex", "CFRIP", "conprotect", "CTD", "drylin", "dry-tech", "dryspin", "easy chain", "e-chain", "e-chain systems", "e-ketten", "e-kettensysteme", "e-skin", "energy chain", "energy chain systems", "flizz", "iglide", "iglidur", "igubal", "ibow", "invis", "manus", "motion plastics", "pikchain", "readychain", "readycable", "speedigus", "triflex", "twisterchain", "plastics for longer life", "robotlink", "xiros", "xirodur" and "vector" are legally protected trademarks in the Federal Republic of Germany and, where applicable, in some foreign countries.