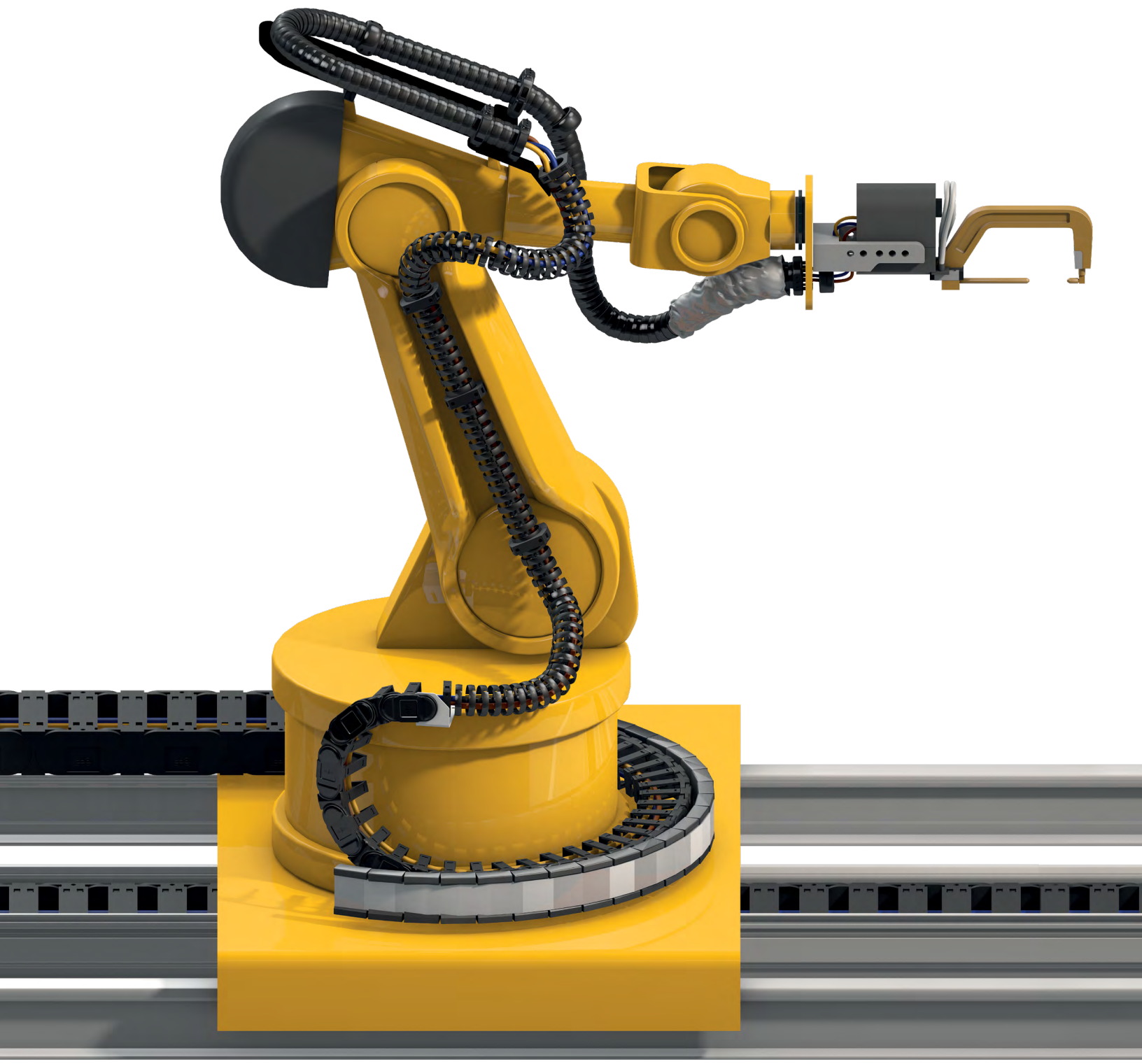

WHITE PAPER:

Energy supply systems for 6-axis robots

Protective hoses versus modular multi-axis energy supply chains

igus®

The problem

The demand for industrial robots continues to increase rapidly. Having registered a record year with 517,000 units in 2021, the latest statistics from the International Federation of Robotics (IFR) for 2022 point to a further growth in sales by 10 percent. These high growth rates will continue in the near future. Even if the cyclical developments in the two main customer sectors, the automotive and electronics sectors, lead to fluctuations in demand, both industries display a strong trend towards making more investments in robotic systems and production automation. In addition, the orders for robotics rise constantly in other segments of the plastics, pharmaceutical and food industries up to the metal and machine sector. Demand from Asia, especially China, will probably provide an even bigger boost to the market by the end of the decade.

With the increasing demand, the requirements on manufacturers and suppliers in robotics are also rising. The competition has intensified significantly. New companies are entering the market and increase the cost and price pressures among the established ones. The booming robot market in China with its growing national competition is a striking example of this trend. At the same time the widening spectrum of applications demands ever more specialized and complex solutions. This applies to the entire system as well as for the individual components. The twin challenges of technological progress and cost efficiency are expressed very clearly in the specific case of the energy supply, the umbilical cord of the robot. Especially in 6-axis robots, which are designed to provide maximum freedom of handling in modern automation, the secure and flexible energy supply becomes a core problem in terms of design and materials. Therefore, a choice has to be made between two alternative solutions — protective hoses and energy chains. Both options provide basic advantages and disadvantages in terms of the aspects of reliability, cost and performance.

6-axis robot: maximum mobility in all directions

The tasks for industrial robots have expanded continuously since their introduction in the early 1960s. Today joining, handling, painting, transporting, loading and unloading as well as assembling are done by robots all over the world and often around the clock. The higher levels of precision and speed, as well as the technical possibilities in the field of kinematics and control, have led to the development of robotic systems that have six degrees of freedom with virtually the same freedom of movement as the human arm. Since the introduction of FAMULUS with its six electromechanically driven axes by KUKA in 1973, such 6-axis robots have become an integral part of innovative industrial sectors such as the automotive industry.

Current types combine the degrees of freedom of the 6-axis operation with increasing loads and a reduction in the required working space. Complex parts handling and multi-stage assembly can be accomplished by more space-saving systems with smaller rotary radii and larger rotational ranges. Significant factors in the optimization are improvements in the design and the joint geometry. However, the lower space requirement means additional challenges for the integration of the supply of media and energy. These are faced first in the configuration, but subsequently in the operation and maintenance of the robot. Tough, reliable, low-maintenance and installation-friendly energy supply systems have become more important than ever.

Profiled protective hoses: The simple and cost-effective solution

In most 6-axis robot applications today one finds corrugated hoses made of specially modified polymers. In appearance they are similar to simple profiled ductwork and are used for cable protection, but are specially optimized for robotic applications to ensure a long service life. Their function is to route the cables and protect them at the same time. The most commonly used materials for hoses are polyurethane (PU) and polyamide (PA). These polymer groups are relatively cost-effective when industrially produced and sold by the meter, which is a major reason for their large market penetration.

Protective hoses made of modified plastics, such as the highly flexible PMAFLEX PIS/PIH corrugated tubes from igus®, are widely used for cable protection, e.g. in robotics.
Source: igus® GmbH

Multi-axis energy supply chains: The more complex and expensive solution

Compared to simple protective hoses, there is no doubt that energy chains are a more complex and thus more expensive solution. Every meter of the chains comprises approx. 30 to 100 individual components or links, usually made of polyamide (PA) (with or without fiberglass reinforcement) or the thermoplastic polymer polyoxymethylene (POM). The modular structure enables the chains to be flexibly adapted to the application. This means that chains can be easily extended or shortened and are simple to assemble and maintain. Most systems can be accessed from the outside, speeding up the initial installation process and any necessary repair activities. In particular, when using pre-assembled cables, cables with large connectors or hoses with fittings, which can generally only be inserted from outside, the assembly, replacement and downtime periods can be significantly reduced.

An example of a multi-axis energy chain is the triflex® R from igus®, which was specifically developed for robotics to achieve modularity, durability, safety and ease of installation: the TRCF series shown here has a special snap lock for even faster opening
Source: igus® GmbH

A decisive characteristic of multi-axis energy chains is that they can comply with minimum bend radii and torsion angles accurately. In conjunction with appropriately developed torsion cables, maximum service life and high reliability can be achieved. Overall, it can be clearly seen that the multi-axis energy chains have been specifically developed as components for cable guidance in robots. Their design and modular nature is directly aligned with the needs of robotics.

Detailed comparison of the two energy supply systems

In the selection of the adequate system, it is valid to correctly assess the needs of each specific application as well as to have a general knowledge of the advantages and disadvantages of the two alternative energy supply systems. A direct comparison offers the best orientation for it. One can generally classify and assess the comparative properties of protective hoses and multi-axis energy supply chains according to seventeen different criteria.

Efficiency in purchasing and installing:

In terms of purchase cost, protective hoses are more affordable than multi-axis energy chains, since it is treated as a by-the-meter item in production. Differences in quality among the protective tubes relate almost exclusively to the use of different materials. The multi-axis chains consisting of many individual components are, in contrast, more complex, on the one hand due to the number of components used, and on the other because of the materials (fiberglass reinforced PA and thermoplastic POM). In addition, the individual parts need to be assembled, which means additional costs in production.

Operating efficiency:

In the event of a defect when using protective hoses, the complete hose system must be changed. The quick replacement of individual cables is not possible, because the connectors to be used can be connected to the appropriate cable only after routing the cables through the protective hose. This makes the electrical testing of

the cables difficult and increases the downtime and costs tremendously. In modular multi-axis energy supply chains, however, defective chain links can be individually removed and replaced. This reduces both the cost of repairs and downtime of the robot. Since most multi-axis energy supply chains can be snapped open from the outside, individual cables or hoses can be replaced separately, cheaply and quickly, in case of faults.

Protection of cables/hoses against external influences:

Both systems provide good mechanical protection for cables. The protective hoses are are very flexible by virtue of their material and design, and also sealed. The enclosed modular multi-axis energy supply chains are less flexible due to their predetermined minimum bend radius, but are essentially more rugged and strong against external influences such as pressure or shock loads.

Compliance with minimum bend radius:

Protective hoses do not ensure a defined minimum bend radius. The minimum bend radius of the cables may fall below the set value at any time in the ongoing process, which can lead to damage and failure of the cables. In modular multi-axis energy supply chains, a strong stopdog system prevents the excessive bending of the cables and thereby reliably increases the operational safety. In this way, long-term failure of the cables is prevented.

Torsion absorption:

Robotic cables are designed to absorb torsional loads. As a standard, usually +/- 180° at one meter length is applicable. Modular multi-axis energy supply chains distribute the occurring torsional load over the entire length and prevent the overloading of cables by defined torsion stops. Protective hoses, however, do not allow torsion by design. The torsion occurring in the application is absorbed only by a swivel joint at the sixth robot axis. A great disadvantage here is the short length of only about 10-20cm (measured from the outlet of swivel-mounted protective hose up to the strain relief), in which the whole torsion takes place. In many cases this causes overloading of cables and must be regarded as a major weakness of the protective hoses.

Ease of installation for filling:

The ease of installation is significantly higher in modular multi-axis energy chain systems, because the filling can be inserted into the system from the outside. This means that pre-assembled cables and hoses can be installed very easily and with little effort. Manufacturers such as igus® GmbH have developed special opening mechanisms that ensure a faster filling and reduces the assembly time up to 80 percent. In the case of protective hoses, on the other hand, assembly can often only take place after feeding into the hose, which significantly increases the time and labor costs involved and ultimately slows down and makes the production process considerably more expensive.

Elimination of downtime:

The same is true for the elimination of downtime. The quick access from the outside in multi-axis energy supply systems prevents extended downtime even if a defect in the cables or the energy supply is detected. Targeted replacement of individual components keeps downtime to a minimum and can be done quickly on site relatively easily by trained staff. Protective hoses can likewise be replaced fairly quickly with expertise, but must always be replaced as a whole package, which increases downtime.

Operating reliability:

Both systems have already been used for a long time in a variety of applications in industry and automation. In practice, they have proven to be highly functional, resistant and durable, i.e. they are both proven and tested types of energy supply in robotics. Their operational reliability is now rated as very high.

Flexibility in programming:

Since the protective hose has no radii stops, it can be bent very tightly. This has the advantage on the one hand that a lot of positions and angles can be reached. On the other hand, one essential disadvantage is that when bent too tightly (deliberately or accidentally), the cables can be damaged, which often leads to failure. Modular multi-axis energy chain systems have a specified minimum bend radius which ensures that the routed cables are not damaged. Since this can never fall below the minimum, it is possible that higher degrees of freedom are needed depending on the application.

Emergency running properties:

The emergency running properties in a protective hose are significantly higher than in a modular multi-axis energy chain system. If the hose is kinked, it can still be run. In a modular multi-axis energy chain system, the chain link is destroyed when falling below the minimum bend radius. As the cable protection is of paramount concern, it is the chain link that is damaged before the cable gets damaged. This, of course, adversely affects the emergency running property.

Versatility of the program:

Protective hoses are produced by the meter and have to offer what you see at first glance. The most you can choose is from a selection of material and type of connections. With multi-axis energy supply chains, the versatility of the product range depends on the choice of the manufacturer and may therefore diverge greatly. The largest and most comprehensive range is offered by igus® GmbH in Cologne.

Retraction systems:

Protective hose systems usually use a retraction system with a compression spring. The downside is a rapidly increasing retraction force, even in preloaded systems. There are three different options in modular multi-axis energy chain systems:

Pneumatic retraction systems — retraction of the energy chain by means of a pneumatic cylinder (the pneumatic cylinder is not driven, but used as a passive gas spring) and a guide roller; the advantage is an almost constant retraction force in any position and the adjustability of the retraction force; it is a relatively complex system with a corresponding price level.

Retraction forces with spring rods — the retraction force is applied by two fiberglass rods; the force progression is rising and not linear; there is virtually no setting option for the retraction force, but is a cost-effective solution.

Balancer — the multi-axis energy chain is retracted into a box by means of a “balancer”; no linear force progression; more space needed.

Accessories:

Both systems have a wide range of accessories depending on the manufacturer, such as retraction systems, gliding feedthroughs, mounting brackets, clamps for the 6th axis of the robot, etc. The modular multi-axis energy chain systems have a greater variety of accessories. igus® GmbH offers, for example, mounting brackets with strain relief teeth for easy mounting, so that cables and hoses can be fixed with cable ties for strain relief easily and quickly, or even mounting brackets as intermediate connection with which the energy chain can be attached or supported at any desired location.

Flexibility in installation:

The length of a modular multi-axis energy chain system can be easily adapted. Depending on the requirements of the individual application, chain links can be added or removed. Protective hoses can indeed be shortened by cutting the required length, but an extension is not possible. In this case, there is only the option of buying a new protective hose and installing it.

Ease of installation at defective locations:

In protective hoses, defective points are more difficult to detect as well as to replace than in multi-axis energy chains. For the latter, it is sufficient to remove and replace the single defective chain link, whereas in protective hoses only the replacement and refilling of the entire energy supply can be considered.

Degrees of freedom in the process:

The high degree of freedom is an essential feature for 6-axis robots, which explains their widespread use in automation. Protective hoses limit this less than multi-axis energy supply chains and superbly fulfill the criterion according to this. The predefined bend radii and especially the minimum bend radius of multi-axis energy chains increase the reliability of the applications and the service life of the cables, but must make compromises for that on the degrees of freedom in the process.

Load capacity:

The load capacity of both energy supply systems is dependent on the choice of materials used and the respective manufacturers. High accelerations and direction changes are typical of robotic motions. The user should therefore pay attention to quality and performance. In addition to choosing the right material, such as fiberglass reinforced polyamides, there are additional mechanisms to withstand specific loads. igus® GmbH has developed the 'trailer principle' to accommodate high tensile forces and hold together the chain links. A tensile force of up to 1000N can be withstood in this way and the breaking force is also many times higher than "normal" energy chains.

Overall assessment:

Overall, the multi-axis energy chains have superior advantages over protective hoses. The main aspect that speaks in favor for profiled protective hoses is certainly the lesser cost. However, every user of 6-axis robots should consider whether this initial financial benefit is compensated by the multi-axis energy chains in the medium term, or rather even reversed in the long-term. The reliability of energy chains in operation guarantees a smooth, failure-free production, which more than justifies the higher initial cost.

Automotive engineering: special challenges for robotics and energy supply systems

The production conditions in the automotive industry have produced their own requirements. A distinction can be made between individual serial applications for which specific standards are established, such as welding or handling, and the more general applications such as riveting, screw fitting, laser welding, friction welding, coating, gripping and very special handling tasks for which individual solutions have to be found. In the standard method, packages are defined, which are then applied to large quantities cost-effectively. However, this standardization does not take place for all manufacturers. Each manufacturer defines his/her own standard package. The need to find individual solutions is of course even more pressing in the case of non-standard methods. Because, all applications that are not covered by a standard package cause a significantly higher planning and production expenditure for users as well as the suppliers.

A special challenge for robotics in the automotive industry are applications with docking systems. Here, different applications can be implemented with only one robot. For the 6-axis robot, this means that in the sixth axis in the program sequence, the tool must be replaced or the entire application changed. For example, applications where multiple welding guns are used is increasingly common. If too many different technologies are used in the process, the whole system becomes more and more complex, requiring more space and potentially also becoming more susceptible to failure. Intelligent solutions that are flexible and easily adaptable for customization are therefore particularly suitable. One such is undoubtedly the multi-axis energy chain system which, due to its modular design and versatility, enables a perfectly customized solution for any particular application.

Property	Protective hoses	Multi-axis e-chains
Economic efficiency in procurement/installation	X	XXX
Operating efficiency	XXX	X
Protection of cables/hoses	XX	X
Compliance with minimum bend radius	XXX	X
Torsion absorption	XXX	X
Ease of installation for filling	XXX	X
Elimination of downtime	XXX	X
Operating reliability	XX	XX
Flexibility in programming	X	XX
Emergency running properties	X	XXX
Versatility of the programme	XX	XX
Retraction systems	XX	X
Accessories	XX	X
Flexibility in installation	XX	X
Ease of installation at defective locations	XXX	X
Degrees of freedom in the process	X	XXX
Load capacity	XX	XX
Total points:	**36**	**27**
Overall rating:	**2.12**	**1.59**

Comparison matrix on the advantages and disadvantages of protective hoses and multi-axis e-chains for 6-axis robots (Evaluation according to the score xxx = satisfactory, xx = good and x = very good; overall rating from the quotient of total points/number of evaluation criteria).

Summary

The development of modern industrial robotics is progressing rapidly and provides systems with ever higher throughput rates and increasingly lower cycle times. Thus, the requirements on the energy supply system are growing immensely. The technological progress on the part of the robot must therefore also be matched by the energy supply. This is the only way to achieve plant reliability and to prevent downtime and maintenance times and thus reduce costs. Quality, durability and greater availability of the robot are more important than the material cost of the components. Because, efficiency and economy can ultimately only be improved by planning and project-safe components. Modular multi-axis energy supply chains are the best guarantee for this given the current state of technology, and due to their flexibility offers the greater potential to address the many challenges in the future technology of robots.