WHITE PAPER:

How Smart Plastics decrease plant downtime while ensuring process conformity through industrial IoT

Predictive maintenance: step by step towards a smart energy chain

The energy chain is a component in mechanical engineering that guides and protects flexible, pneumatic or hydraulic cables. Energy chains are used wherever moving machine parts need to be supplied with energy, data, liquids or gases. If the energy supply system fails and/or a cable breaks, the whole machine often stops. It is therefore important to pay close attention to a supposed “C-part” in the overall consideration of machine availability, because a system failure or unscheduled machine downtime are among the biggest cost drivers in industry. A study by FM Global - one of the world’s largest industrial property insurers - shows this: in 2018, the insurer counted 232 major losses, each with a loss value of more than $3million. In 28% of the cases, it was due to system failure. 62% of the damage caused by system failures was due to inadequate maintenance, which ultimately accounted for three quarters of the claims payments made.[1)] More and more condition monitoring systems and solutions for predictive maintenance are therefore called for by maintenance personnel, which make maintenance plannable and prevent unplanned failures in good time.

PART 1

In the beginning was condition monitoring

Companies engaged in various industries have already gained initial experience with condition monitoring of drive components. Components such as electric motors or rolling bearings are equipped with sensors that record one or more parameters, e. g. temperature or sound waves/vibrations. A condition monitoring system records the values and issues an alarm message when a defined limit value is reached. These systems can be found in applications with very high demands on safety and availability, e.g. in the wheel drives of rail vehicles and in wind turbines.

energy chain and cables destroyed by a blockage in the guide channel.
Source: igus®

When it really matters: monitoring energy chains

What about energy chains? Their availability must also be ensured - as mentioned at the beginning. The specific requirements are as varied as the areas of application.

Some examples
Energy chains in sewage treatment plants run very slowly in 24/7 operation under adverse environmental conditions without supervision. For example, leaves and ice can clog the system up. In the worst case, the moving end of the energy supply system rips the entire energy chain out of the guide trough and damages the cables until they break. In such a case, the result is often a complete replacement of the system with downtime of several days to weeks!

[1] Source: https://www.experten.de/2019/07/26/anlagenausfaelle-verursachten-fast-ein-drittel-aller-sachschaeden/

In crane systems, such as container cranes, maximum availability is required. There is strong competition between ports. As far as unloading fees are concerned, sometimes cents and minutes decide which port the logistics company chooses for unloading. If only four cranes instead of five can unload a ship due to a damaged energy supply system, this extends the unloading time of the other cranes by 8-10 hours and increases costs by up to 25%. The loss of time also delays all other planned loading times for the ship at the next terminal. This quickly results in time losses of several days before the ship can start its overseas voyage. The latest generations, the so-called Triple E-Class STS cranes, in turn present further challenges for the entire energy supply system, which is presented separately in another igus® white paper.

Triple E-Class container ship
Source: Von Walter Rademacher / Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=27770342:

A third application example for condition monitoring is automated plants in the automotive industry, which operate at very high cycle rates. The energy chains quickly reach cycles in the millions. There is hardly any other industry in which reliability is as important as in this branch of industry. Entire vehicles or individual components such as engine parts pass through production on the assembly line and with a high degree of automation. If a part comes to a standstill here, this quickly leads to expensive production losses, which also affect the suppliers’ supply chain. It is therefore important for vehicle manufacturers and suppliers to be able to procure reliable components.

Engine plant in Austria
Source: igus®

In all three cases, energy chains can be equipped in such a way that they monitor their condition automatically and switch off the machine and/or plant before a total failure occurs.

Prerequisite: “built-in” sensor technology

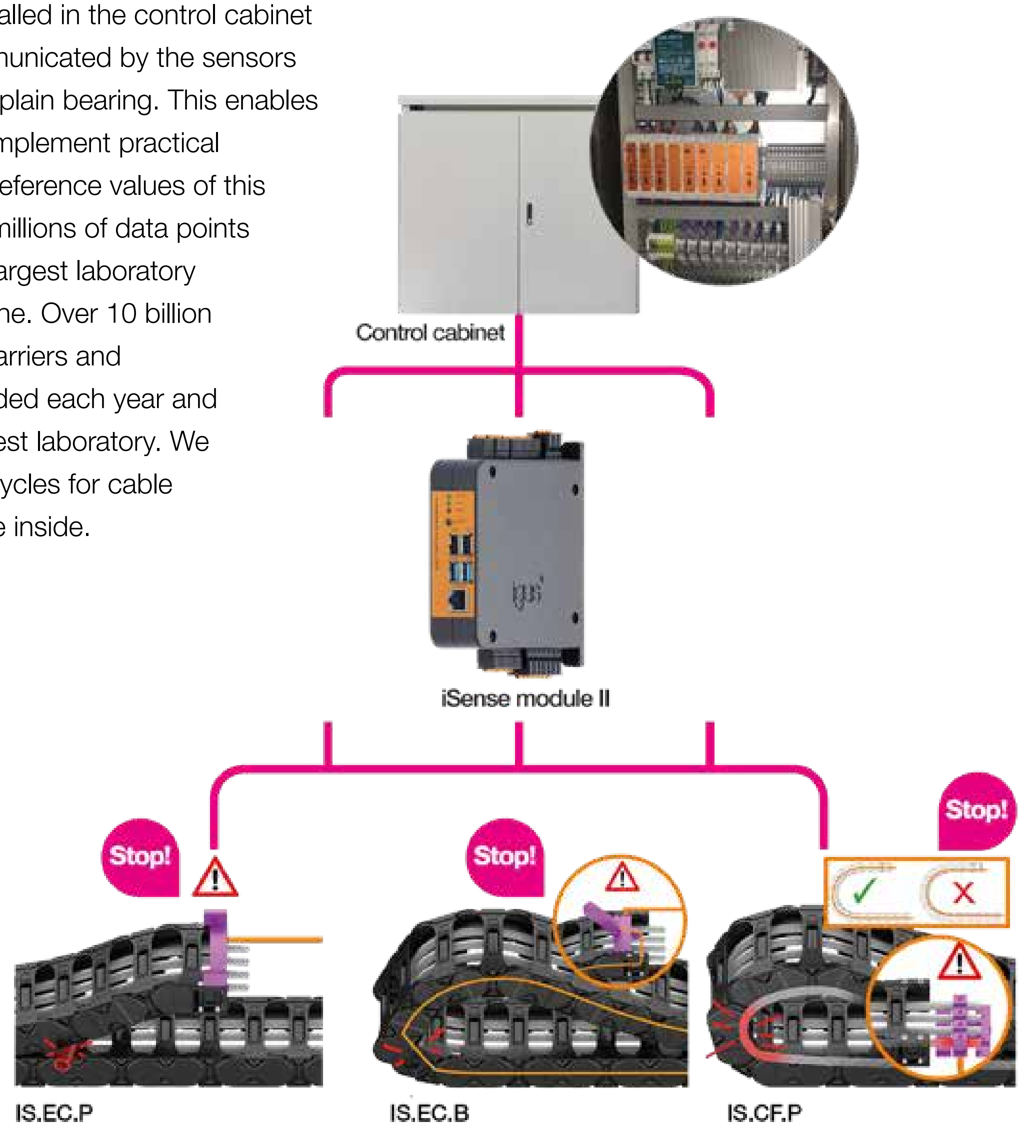
The prerequisite for this was created by igus® with the development of “smart plastics”. These are sensors and monitoring modules that bring intelligence to plastic products - in this case energy chains and plain bearings. For this condition monitoring task, igus® has developed the i.Sense system with various options:

i.Sense EC.P: push/pull force monitoring - force measuring sensors mounted on the moving end detect the force required to move the chain over the travel during operation. The push/pull forces are transmitted to a module in the machine control cabinet, which, if the pre-set force limits are exceeded, sends a signal via an NC contact to the customer’s control system, which usually stops the machine as quickly as possible. The EC.P (formerly PPDS) push/pull detection system has been in use for more than 10 years in over 1000 installations and has become a standard feature for crane manufacturers and operators (e.g. on stackers/reclaimers).

i.Sense EC.B: breakage detection
An inflexible special rope is guided by separators in the neutral axis of an energy chain system and is connected to a length measuring system at the end of the rope. In case of a break in the energy chain or even a single side part of the energy chain, the system detects this relative change in length of the rope and also switches off the system via the NC contact. Thanks to the early detection of the breakage of a side part, the system can be ready for operation again with a very short repair time of just a few minutes. The EC.B breakage detection system has already been used hundreds of times on linear robots, e.g. in automotive production.

i.Sense CF.P: cable pull force monitoring
For long travels, e.g. on crane systems, the cable tails must be checked regularly and readjusted if necessary. If this inspection and, if necessary, readjustment is not performed, in the worst case the inner crossbar will abrade the outer jacket of the cable. As a consequence, short circuits can lead to cable fires or protracted failures. The CF.P system measures the increased tensile forces at the strain relief clamps, so that here too, timely information can be given to the plant operator.

The evaluation module installed in the control cabinet evaluates the signals communicated by the sensors on the energy chain or the plain bearing. This enables users of energy chains to implement practical condition monitoring. The reference values of this evaluation come from the millions of data points collected in the industry's largest laboratory operated by igus® in Cologne. Over 10 billion cycles for e-chain® cable carriers and chainflex® cables are recorded each year and then evaluated within our test laboratory. We also perform 3 billion test cycles for cable carriers alone without cable inside.



Sensor systems from igus® smart plastics® in condition monitoring
Source: igus®

PART 2

The next development stage: from condition monitoring to predictive maintenance

According to igus®, condition monitoring is only the first stage of development. Predictive maintenance is the next step towards implementing a comprehensive concept of smart energy supply systems. This is implemented with the i.Cee system, which is available in different versions.

The advantages of predictive maintenance
With the i.Cee system, the user takes a step towards the use of smart components made of high-performance polymers equipped with "built-in intelligence". This gives various advantages when using energy chains as well as plain bearings.

Retrofit: save costs through maximum utilization of the components
Predictive maintenance involves the replacement of moving components such as energy chain systems or plain bearings at (usually carefully defined) regular intervals, which are shorter than the expected service life. However, this means that the components are replaced when they are still operational. If they are replaced shortly before they reach the end of their actual life, the service life can sometimes be significantly extended, often even doubled. This then halves the costs and reduces the maintenance effort - without compromising reliability.

Avoid high costs due to unexpected machine downtime/failures
If irregularities occur during operation and before the specific end of service life is reached (e.g. due to an accident or the presence of contaminants), the system can detect these irregularities and issue a warning message. The user is then able to eliminate the unusual operating condition before major damage occurs. In the "worst case", downtime costs of approximately $2,500 to $5,000 per minute are incurred in some industries.

Minimize service and maintenance costs
For large energy chain systems, compliance with the maintenance instructions is essential for maximum service life. The i.Cee system reminds the customer of upcoming inspections or maintenance work. This information is provided according to use, so that longer maintenance intervals are possible with less use, thus saving costs. This also applies to plain bearing applications. Here, adherence to the maintenance instructions prevents costly damage to shafts or the bearing seat.

Integration into networked IT systems

An increasing number of production plants are recognizing the savings potential offered by networking machines and machine components at the data and IT level, right through to cross-company networking through overarching standards such as OPC UA. Here there are further (cost) advantages in the use of energy chain and plain bearing systems with “built-in” predictive maintenance. All sensor data - e.g. the calculations of the individual service life and the resulting notification - can be passed on to higher-level IT systems and evaluated or documented there. This includes Management Execution Systems (MES), Zero-Downtime- Systems (ZDT) and software for company-wide maintenance.

Smart “preventive maintenance” - with i.Cee

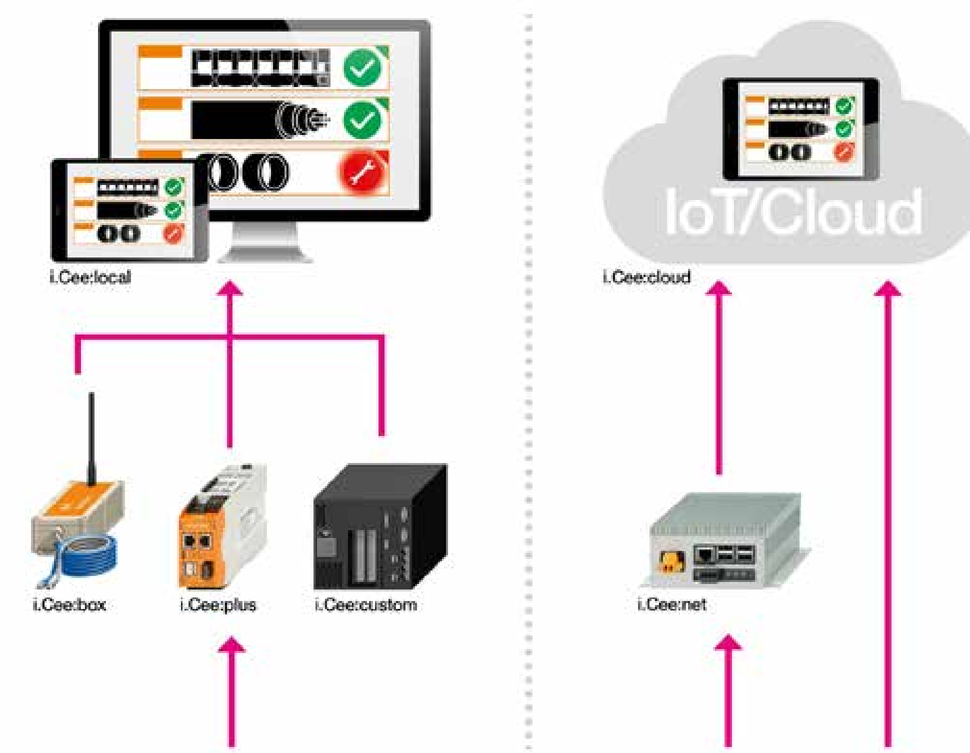
As an intelligent “preventive maintenance” system, i.Cee consists of three levels: sensors, hardware and data collection/evaluation. At the heart of the system is the software. It creates the conditions for an intelligent, condition-based and individual service life calculation and continuous monitoring of an energy chain or plain bearing system.

Learning software

The i.Cee software calculates the service life of an energy chain on the basis of the actual load. This works as follows:

When the operation or software is started, the service life is compared with the algorithms of the current online service life calculator. The manually recorded environmental and movement data is applied, and the double strokes and/or kilometer readings are transferred to the software. It converts the data in terms of days. This results in the service life to the recommended replacement, assuming the anticipated movement data with 24/7 use and assumes constant impact of the worst environmental data. In this way when commissioning the i.Cee System, the “worst case scenario” is assumed, which is quickly put into perspective with the service life and the amount of real data collected.

During operation, the system records the actual loads of the application in real use - e.g. intermittent operation and pauses/interruptions as well as, depending on the used sensor technology (see below), temperature fluctuations, vibrations, lateral accelerations, chemical influences, abrasive media and so on. On this basis, the remaining service life is continuously recalculated - assuming the actual motion and load profile for further operation. If an Internet connection is available or i.Cee:net is used (see following diagram), the online service life calculators of the components used are regularly queried at the same time and the display of the remaining service life is adjusted accordingly. When using i.Cee:local without an Internet connection (see following diagram), if there is a serious deviation in the movement and environmental data, a temporary, manual query is requested from the customer’s system, in order to adapt the service life calculator to the actual conditions.



Two options for data transmission
Source: igus®

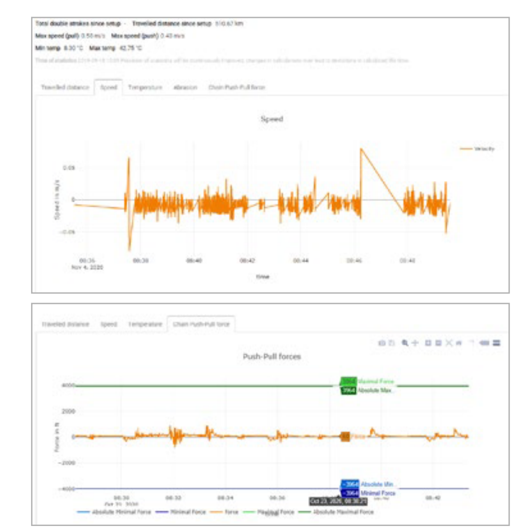
Sensors record real operating data

Abrasion and wear sensors, which are also installed in or attached to the igus® products used (e.g. in the sliding surface, in the pin-bore diameter, or in the side-wall), ensure a further comparison with the real conditions to which the respective igus® product is exposed in the application.

The sensors transmit information on the percentage lifetime status of the polymer components subject to abrasion. This sensor information “overwrites” the given calculations so that, as mentioned above, the forecasts become increasingly more accurate as the operation progresses and change from a “worst case scenario” to an adaptive, learning scenario. (i.Cee:local and i.Cee:net). Another cornerstone for precise, scheduled and predictive maintenance.

Provide inspection proposals and real-time information

Based on the calculations shown above, the customer receives information for inspection and maintenance planning for selected igus® products, based on the maintenance recommendations provided by the empirical values gathered over several years in the field of energy supply and bearing technology.



Example of a smart plastic dashboard
Source: igus®

Calculate and issue predictive maintenance information

Both the above-mentioned sensors for service life calculation and the i.Sense sensor units for condition information provide data from which, in many cases, indicators for premature wear of the product or the risk of product failure can be determined at a very early stage. Based on the experience gained in the industry's largest test laboratory, spread over 41,000 ft²., for plain bearings and energy transmission solutions, and in combination with self-developed algorithms, the system alerts and informs the user at an early stage about possible failure risks.

Three hardware concepts are available for the use of i.Cee:software in i.Cee:local:

1. i.Cee:box: the necessary IT hardware is installed together with the LoRa receiver antenna in a housing outside the customer's control cabinet. The i.Cee:box may contain additional sensor and connectivity technologies.

2. i.Cee:plus: this is an existing industrial PC, which is installed on the top-hat (DIN) rail in the customer's control cabinet. The LoRa receiver antenna is fixed in a small additional housing, also on the outside of the customer's control cabinet.

3. i.Cee:custom: the igus® i.Cee software is installed on the customer's hardware based on a licensed model. Only the LoRa connectivity is implemented as external hardware (currently only the concept exists - it is developed together with the customer if necessary).

The installed i.Cee:sensors currently use the LoRaWAN radio transmission method, by which ranges of 150m or more can be achieved.
What data is determined by which sensors for predictive maintenance (i.Cee) and how is it made available?

Options to determine the motion profile:

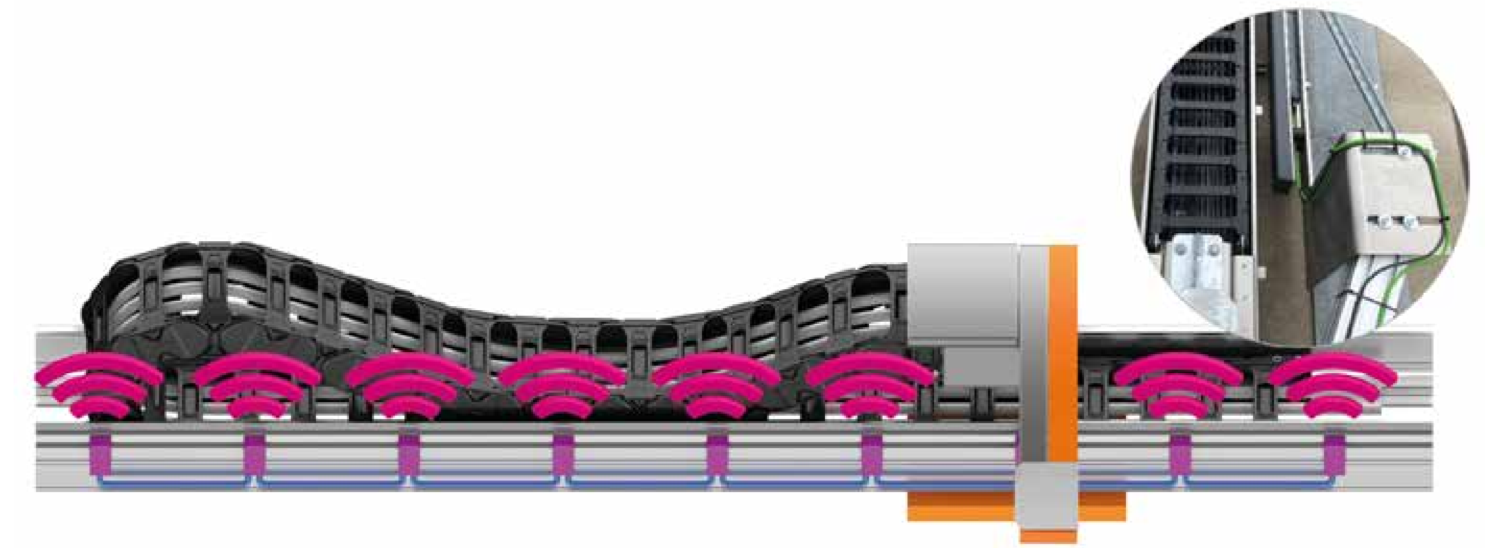
1. Connection to the customer control system

In the Siemens S7 series control systems from type 1200 or higher, the values for travel and/or cycles are read directly from the corresponding variables (flags) and the current position of the trolley/moving end is transferred to the i.Cee system. Other control systems often have an "OPC UA" server. In this case the values are transferred directly from the OPC UA server to the igus® system. If this option is available, reading out the control system is the most precise and the most cost-effective way of communicating the movement information of the machine to the i.Cee system. Communication between the Siemens PLC and the igus® I.Cee:local hardware takes place, for example, via the TCP protocol extension according to RFC1006 via the Ethernet network topology.

2. Sensors provided by igus® and installed on the product to record the motion profile

Abrasion sensors such as EC.W and EC.I are also equipped with an acceleration sensor, which makes it possible to create a motion profile. By direction changes and measuring the time of motion, the system calculates a motion profile and thus obtains the information for calculating the service life and determining the next maintenance date.

For very long travels (>500m), the position and motion profile can also be determined via a GPS/Glonass satellite receiver.
The EC.PP system offers a further, even more precise way of determining the motion profile. This position measuring system can be used for travels with a guide trough. Beacons, which are connected by cable, are attached to the outer side parts of the guide troughs at 50cm intervals. These beacons remotely transmit their positions to a single antenna fixed to the floating moving end. The system calculates the trolley position from the relative position of the beacon to the antenna and the position of transmission. This is transmitted to the control system via Profinet. The desired repeatability is specified as +/-2mm.



24/7 endurance test in the igus® outdoor laboratory. P4.1 rol energy chain and EC.PP
Source: igus®

In addition to the options mentioned above, classic external systems such as laser, bar code and radar systems can also be used. The communication is usually carried out via classic systems - e.g. 4-20 mA technology.

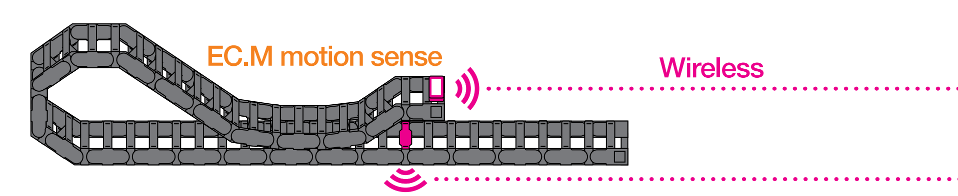
Options to determine the abrasion:

In most cases a so-called "loop sensor" is used. Here conductive elements are inserted into the plastic at precisely defined points. The position of the sensors is relative to the percentage of abrasion, so that in case of interruption and reaching an exactly defined percentage of abrasion, the theoretical calculation of the igus® algorithm is adapted to the actual remaining service life.

Sensors to determine abrasion

• EC.W (Generation 1) the system detects the abrasion of the wear pads on the side parts of the energy chain via the resulting proximity of the crossbars. The end of the service life of the product is reached when the crossbars of the upper and lower run (the upper moving part of the energy chain and the lower part) touch each other.

Crossbar with single-layer wear element, battery powered, ZigBee radio transmission technology
Source: igus®

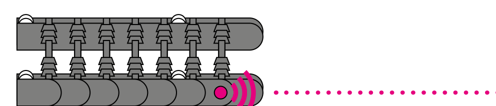


• EC.W.LTE (Generation 2) with solar energy supply or solar-buffered battery operation for use with i.Cee. cloud: 2nd generation; the sensor has a 4-layer structure, which enables even more precise prediction of the service life, and on the other hand, communication with the i.Cee System takes place directly from the crossbar via the cloud.

Source: igus®

• EC.W.LoRa with solar energy supply for use with i.Cee.local: the sensor is installed vertically in the separator together with the evaluation unit and the LoRa transmitter unit. Energy is supplied by a solar-buffered accumulator circuit, which is installed horizontally between the crossbars in the outer radius. The system measures the abrasion of the wear pads on the side parts of the energy chain. The side parts of an energy chain are always a few millimeters higher than the connection point of the crossbars. As the two chain sections slide on top of each other, the distance between the crossbars is reduced (following diagram). The end of the service life is considered to be reached when the crossbars of the upper and lower runs touch. The exchangeable, four-stage abrasion sensor is manufactured using a 3D printing process and the per cent-steps are stored in a database. The loop conditions are transmitted to the i.Cee:local hardware using the LoRa radio transmission technology. In addition, acceleration sensors are fitted for motion estimation in applications without PLC connection.

• EC.I (only in connection with i.Cee:net): the system determines the clearance between pin and bore connection via the offset to a magnet attached to the next chain link. Connection to i.Cee.net via cable ZB.I



Source: igus®

Source: igus®

• EC.I.LoRa (i.Cee:local) with solar-buffered energy supply: the system consists of two separators, which “simulate” a chain link at the pivot point of the side part. Any clearance between the pin and bore connection in the two side parts is thus transferred to the “sacrificial chain link”. Here too, conductive elements are arranged relatively to one or more percentage wear stages. The loop conditions are transmitted to the i.Cee:local hardware using LoRa radio transmission technology. In addition, acceleration sensors are fitted for motion estimation in applications without PLC connection.

• EC.I.LTE (i.Cee:cloud) with solar energy supply: functional principle as for EC.I.LoRa, except that the sensor data is sent directly from the crossbar to the cloud via mobile radio.

• EC.B (i.Sense): due to the functional principle of the EC.B system (see above section Condition monitoring) it is possible to detect the wear of the pin/bore connection of an energy chain also via the EC.B sensor. The special rope is able to measure the change in condition of an e-chain® during its service life. These changes are transmitted to the i.Cee software, which calculates a service life in terms of days. The only requirement is that the sensor is connected to the i.Cee:local system via UART to TTL converter.

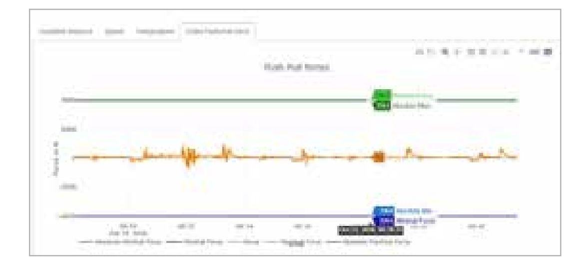
Output information and channels of the i.Cee System

Output information

- Time until the recommended replacement of the igus® components
- Time until the next scheduled maintenance
- Time until the next unscheduled inspection
- Condition information of the overall system and all sub-components
- Alarm in case of malfunction
- Predictive maintenance information
- Sensor raw data of the energy chain or plain bearing
- Triggering the error messages stored in the PLC error memory

Output channels via the i.Cee System

- i.Cee:cloud: output via web interface to PC, tablet or mobile phone. E-mail, SMS, sensor data download
- i.Cee:local: graphical output of all information on a local dashboard. Access by web browser via Ethernet from the local network (http access via local IP address)
- The customer is provided with all raw sensor data for further processing in their own industry 4.0 concepts or for analysis purposes



Example of a smart plastic dashboard
Source: igus®

Further output channels

1. Direct connection to Siemens S7>1200 PLC: the system describes appropriate variables reserved by the customer either with corresponding values (integer) or Boolean operators by which corresponding messages are then triggered from the message memory. As a rule, the variable definitions are determined in advance by the customer and the i.Cee.local hardware is delivered pre-configured accordingly.
2. For control systems of many other manufacturers, the above information can be provided on a “OPC UA” server. In both cases, the messages are displayed on the system monitor/control panel or teach panel.
3. An OPTIONAL connection to the existing igus® cloud is in development. Here the raw data is either transferred to the igus® cloud as a serial data stream via an uncompromisable communication channel or it is connected via a secure VPN tunnel in close consultation with the customer’s IT team.

4. In case of a desired connection to MES/SCADA or other local network services, all messages can be displayed via:
   • JSON File via MQTT Broker
   • REST via HTTP
   • Text or .CSV file

   In such a case, raw sensor data is managed via SMB protocol in the customer network or via read access to the internal drive of the i.Cee:local device.
5. The integration into the FANUC Field System environment is very advanced. This is an open networking standard from the company Fanuc where all data of all machines and components are transferred in a standardized format via a converter. This data can then be used and displayed/processed by 3rd party software. These applications can be purchased by the customer via an app and installed in the local system. An igus® app, which displays the data in the usual way, analogous to the http dashboard, can also be downloaded from the FIELD System App Store.

Conclusion

The networking between machines and plants is already well underway. igus® offers a comprehensive “ecosystem” for the predictive maintenance of energy chains, comprised of hardware, software, sensor technology, data transmission and connection to the superordinate IT infrastructure. Since this topic is extremely complex, we offer individual consultations to help bring the IIoT (industrial internet of things) into your specific manufacturing environment.

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