Monitoring Strategy for Process Optimisation

The Bosch plant in Bamberg protects chip-forming production with process monitoring system from ARTIS

The reason that the diesel engine in passenger cars has lost its "tractor image" is the introduction of the common rail system by Bosch in 1997. Bosch uses the CTM system from ARTIS to monitor the necessary deep drilling operations during the production of the injectors. This inline monitoring reduces not only the cycle times but also improves the quality of the complete machining process.

Ever since Bosch introduced the common rail system (CRS) for passenger car diesel engines in 1997, car drivers have been very glad about the economical fuel consumption, the highly dynamic driving qualities, and the reduced emissions of their compression-ignition diesel engines. At the present time, almost 40 percent of all new registrations in West Europe are for diesel vehicles in 1991 it was still 15 percent. CRS is a fuel reservoir injection system that differs from all other fuel injection systems in that pressurisation and injection have been separated from each other. The CRS system consists of a low-pressure system with a pre-feed pump and filter, a high-pressure pump, injectors, and an electronic control unit with sensors and a diagnostic interface. The high-pressure pump feeds the fuel into a high-pressure fuel reservoir (rail). There the fuel is constantly available in order to be injected into the cylinders at a pressure precisely adjusted to the engine's operating state. The time of injection and the amount of fuel are individually calculated for each cylinder by the electronic control unit and, depending on the driver's request made by pressing the accelerator pedal, the fuel is then injected via the injectors. Accordingly, the opening and closing of the injector valve mark the beginning and the end of the injection of fuel.

Common Rail System Improves Diesel Engine Technology

While the first CRS generation of 1997 still worked with fuel injection pressures of 1,350 bar, the fuel injection pressure went up to 1,600 bar with the second generation in 2001. As a result, these diesel engines were turned into even more fuel-efficient, lower-emission and quieter engines. As already before, the second-generation solenoid valves also control the precise injection of fuel into the combustion chambers. In the third-generation common rail dating back to the year 2003, the fuel injection system in which piezoelectric inline injectors were used for the first time was an extremely innovative design. Due to their improved switching times, these injectors can be used to meter the amounts of injected fuel even more precisely. Since these injectors work faster than the tried and tested injectors with solenoid valves, the individual injections of fuel can follow each other at shorter intervals of time. The advantage: with the piezoelectric inline injectors, diesel engines are turned into engines that are not only quieter and more fuel-efficient but also cleaner and more powerful.

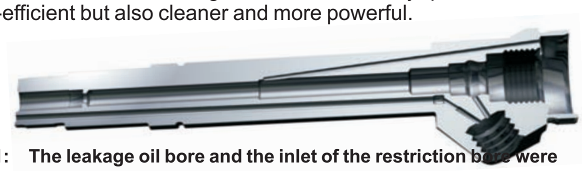

Fig 1: The leakage oil bore and the inlet of the restriction bore were determining factors for the cycle time before the tool monitoring system was introduced.

At Bosch, the 100 millionth common rail injector for passenger car diesel engines left the assembly line at the end of 2005. So far, more than 23 million cars were equipped with that type of injector. At the Bosch plant in Bamberg, and at two other European plant sites, the company also produces the third CRS generation with the piezoelectric inline injectors. For the use of piezoelectric technology, researchers and development engineers at Bosch and Siemens VDO jointly received this year's German Future Award of the Federal President.

Critical Deep-Hole Bores in the Production Process

For the production of the injection holder body, four deep-hole bores are provided: the leakage oil bore, the inlet bore on the valve piece, the inlet restriction bore, and the nozzle inlet bore. Until two years ago, Bosch used a laser to monitor the multiple spindle drill heads of its machining centres for the presence or breakage of tools. For that purpose, the tool carriage with the holding fixtures for the four deep-hole drills crosses the path of the two laser beams before each machining process; an interruption of the beam indicates the presence of the drill but does not provide information on the condition of the drill. With this method, the leakage oil bore and the inlet restriction bore, in particular, were determining factors for the cycle time. After ARTIS had approached Bosch in 2004 and presented its CTM tool monitoring system, Bosch expressed the wish to reduce the cycle time during the production of the injectors by means of an easy to handle, but reliable in-process monitoring system that would replace the laser check prior to the machining process. Both partners decided to use an acoustic emission sensor in order to detect a tool breakage during a machining process.

Fig. 2: Acoustic emission sensors on each clamping point in order to receive an "optimum" signal.

During the implementation of the monitoring system, the team of ARTIS and Bosch staff members initially optimised the position of the acoustic emission sensors in the course of numerous tests. In order to receive an "optimum" signal with as little secondary noise as possible, the total number of four sensors must be positioned close to the metal-cutting point (one sensor for each clamping point), and it is also important to ensure that the number of transmission points is reduced. The acoustic monitoring succeeds with more efficiency the shorter the sonic distance is through the workpiece and the workpiece carrier. Additional series of tests revealed that, although the sensitive monitoring system detects tool breakages immediately, it cannot reliably distinguish between tool breakage and chip jamming or cutting edge chipping. So despite the fact that there was no tool breakage, the machining

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process was stopped by the breakage alarm. The next task is to develop a suitable software strategy and to allocate the various occurrences to the recorded sound spectrums and teach the system accordingly.

Sound Spectrums Reveal Tool Breakage and Wear

During the development of the monitoring strategy, the machining process was examined in detail via the visualisation of the CTM system. The alarm outputs were switched off, and the number and intensity of the signals occurring during the machining process were compared with the condition of the drill after the machining process. The experience gained here resulted in the adaptation of the software and in the definition of a specific signal level and a minimum signal duration above that value. This means that a forced breakage of the tool exists if the measured signal level remains above the defined breakage limit for more than 300 ms. If the signal exceeds that limit three times for more than 40 ms, this is an indication of cutting edge chipping. After a total of 40 instances of this small-scale cutting edge chipping, the tool is considered to be worn and must be replaced. After being taught on that basis, the ARTIS system can now reliably detect a tool breakage during the machining of the injectors and also provide correct information on the state of wear of the cutting edge. The cycle time has been optimised by the in-process monitoring, and alarms are activated only in the event of a tool breakage or wear limit approach. And the drill can be replaced and reground in time before becoming a total loss.

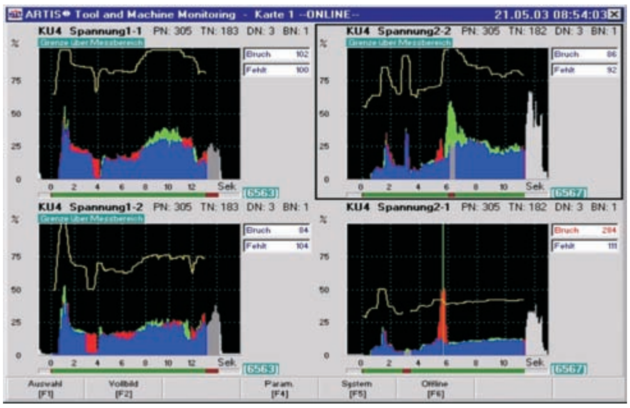

Fig 3: Signal curve for drilling operation before performing the optimisation measures on the monitoring system and on the tool

The CTM (Computer Integrated Tool and Machine Monitoring) system from ARTIS is completely integrated into the machine control system and is used for tool, process and machine condition monitoring. This system, which is designed specifically for large-scale production, detects missing, broken and worn tools in metal-cutting production facilities. The so-called DTA (Digital Torque Adaption) method transmits the current torque values from the drive unit regulators of the spindle and feed drive units via the Profibus to the CTM system, which means that, in many cases, the installation of additional sensors is no longer required. CTM then evaluates this data. The CTM card, as the central monitoring unit, has the form of a PC plug-in card that is equipped with standard interfaces and is inserted into the operator panel of the machine control system. This means that the card requires neither its own housing nor its own power supply. Furthermore, the card is easy to install. The CTM card offers four completely independently operating monitoring channels that may, however, also be interconnected if required.

Sensor System for Acoustic Monitoring of Drills

The sensor system for the acoustic monitoring of the four drills in the multiple spindle heads at Bosch consists of four acoustic emission sensors AE-C and a measuring transducer KU-4. For most applications, the permanent attachment of the acoustic emission sensor AE-C on the machine or on the workpiece clamping device is sufficient. For machining operations in which the sensor does not deliver suitable signals for evaluation, due to, for example, the size of the workpiece or the sound-proofing intermediate layers, the sensor AE-Z is provided. Here, the acoustic emission sensor is pressed onto the workpiece surface by means of a compressed-air cylinder during the machining phases. The measuring transducer KU-4 contains an independently operating collision monitoring system that can be activated via external signal inputs. The collision monitoring system works with three different threshold values for normal machining (operate), tool changes (tool change) and rapid feed (rapid feed). When the sensor is used in the operate mode for the tool monitoring process, the collision monitoring system remains inactive.

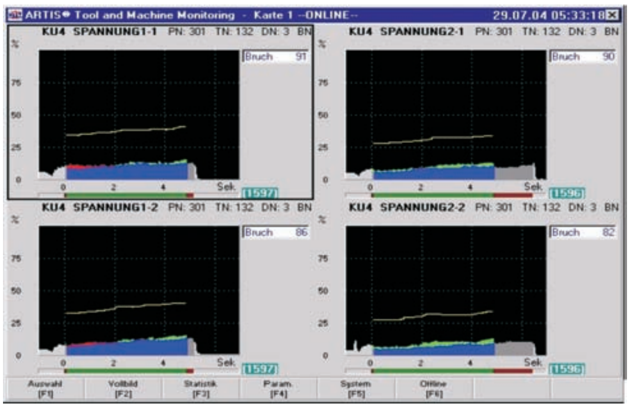

Fig 4: Signal curve for drilling operations after performing the optimisation measures on the monitoring system and on the tool

When the ARTIS monitoring system was introduced, the basic idea was actually to reduce the cycle times by the no longer required use of the laser system. But, in the words of G. Fleischmann (position in the company?) at the Bosch plant in Bamberg: "We have gained much more than only a reliable in-process monitoring system. The data collected and interpreted thanks to the ARTIS system and its process visualisation and documentation has helped us optimise process parameters such as feeds and cutting speeds We were able to reduce the non-productive times and the machining times, increase the output with fewer rejects, upgrade the manufacturing safety as a whole and stabilise the quality of our machining processes." Since the CTM system records the learnt acoustic emission spectrums of the drills, Bosch can also use the deviating signal to identify insufficiently or incorrectly reground drills in order to monitor and improve the quality of the processes in the tool grinding department.

Common Rail The Next Generation

The current common rail generations from Bosch make diesel engines powerful, quiet, and fuel-efficient, and they also ensure low emissions. At the moment, the focus is on two concepts: the second-generation common rail with magnet-controlled injectors and the third generation with piezoelectric inline injectors both with an injection pressure of 1,600 bar. The piezoelectric injectors operate extremely fast and contribute to reducing the emissions by as much as 20 percent. Improvements are also being made in terms of power, consumption and engine noise. Bosch will therefore also be offering both generations on a parallel basis. But the development work still goes on. The fuel injection pressure of the third-generation common rail will be increased to 1,800 bar still in this year, with 2,000 bar being planned for 2007. And a highly dynamic switching valve, even higher fuel injection pressures up to 2,000 bar are planned and higher flexibility will also make the CRS with magnet injectors even more efficient in various applications.

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