MARPOSS

WHITE PAPER

COLLISION AND PROCESS MONITORING

as a Fundamental Enabler for Autonomous Manufacturing

CONTENTS

1. EXECUTIVE SUMMARY

The transition to unmanned manufacturing ("lights-out manufacturing") requires seamless, real-time monitoring of all machining processes. Where no operator can intervene to correct errors, unnoticed tool failures or collisions often lead to significant property damage and days-long downtime. This white paper establishes the market gold standard for autonomous production through the targeted use of the **GENIOR MODULAR** process monitoring system and GEM**CMS** collision monitoring system from Marposs (Artis) in combination with the corresponding visualization and analysis software. It demonstrates how sensor-based monitoring functions as the fundamental nervous system can be used for ghost shifts and process-integrated quality control.

2. INTRODUCTION: THE UNSTOPPABLE TREND TOWARD GHOST SHIFTS

Rising cost pressures, the shortage of qualified machinists, and the need to utilize expensive machine parks around the clock are forcing the industry toward automation. "Lights-Out Manufacturing" describes the vision of a factory that operates with high productively during night and weekend shifts without any personnel – with the lights turned off.

However, this autonomy carries a massive risk: if human sensory perception (hearing abnormal machining noises, seeing chip jams, feeling vibrations) is eliminated, the machine tool loses its final safety mechanism. A single undetected tool breakage at the start of an 8-hour unmanned shift can trigger a cascade of scrap production, quality issues or, in the worst case, destroy the main spindle.

3. USE OF MONITORING SYSTEMS

The use and application of monitoring systems are diverse and span various stages of manufacturing systems.

- Detection of breakage, missing parts, and wear in machining production
- Machine protection and collision detection
- Prevention of scrap, rework, and consequential damage
- Detection of clamping errors, incorrect components, unbalances and faulty processes
- Condition-based monitoring (CBM) of bearings, ball screws and other machine components
- Adaptive control for increasing machine productivity and overload prevention
- Acquisition and processing of process data
- Process visualization, documentation and reporting
- Energy Monitoring of machines and aggregates
- Source of information for other third-party systems
- Data provision for cloud-based systems
- Full filling production specifications for aircraft (e.g. P11TF12), energy management (e.g. ISO 50001) and other

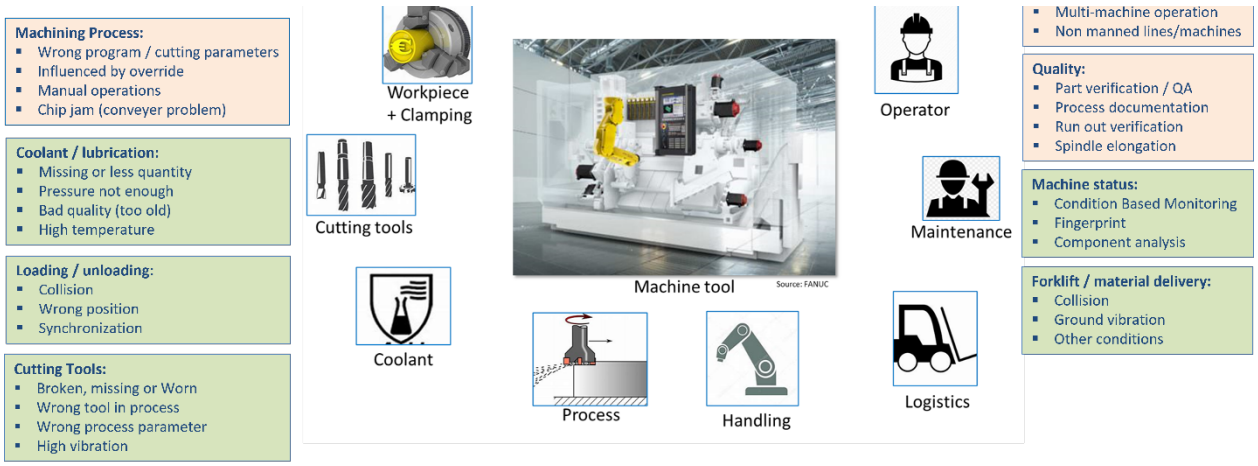


Figure 1: Applications for monitoring systems

4. THE TECHNOLOGICAL NERVOUS SYSTEM: GENIOR MODULAR & GEMCMS

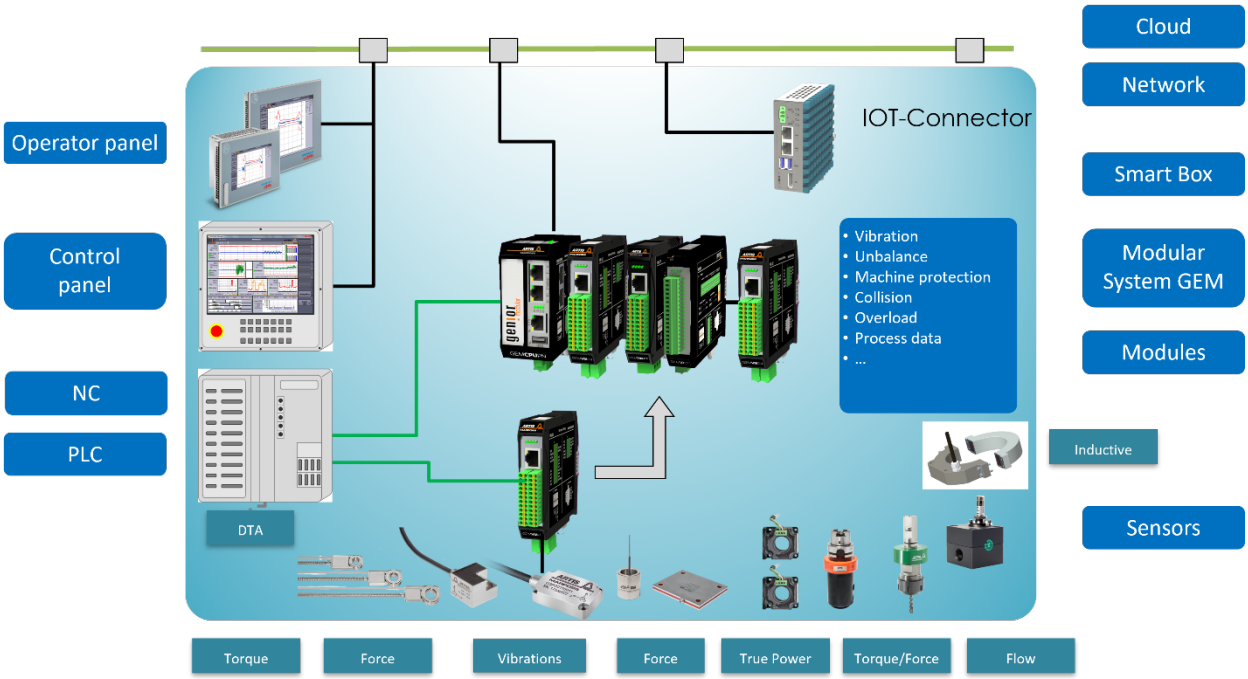
With the Artis monitoring systems, Marposs offers a market-leading solution specifically developed to address the challenges mentioned above. The system consists of the core components sensors, measurement converters and main unit. The visualisation open a window to the machining process.

4.1 GENIOR MODULAR

GENIOR MODULAR is a modular system for protecting tools and machines that is installed in the control cabinet. Using self-contained and extremely fast measurement modules, it processes sensor signals in the millisecond range and can communicate directly with the CNC control via fieldbuses such as Profibus, Profinet and EtherNet/IP to receive interface signals for control and, in turn, trigger feed stops, tool changes or emergency-stop commands.

Vertical integration refers to the alignment of information technology (IT) and operational technology (OT) across different hierarchical levels of a production facility. GENIOR MODULAR achieves this by serving as the data bridge from the raw cutting edge of a machine tool up to executive-level database servers.

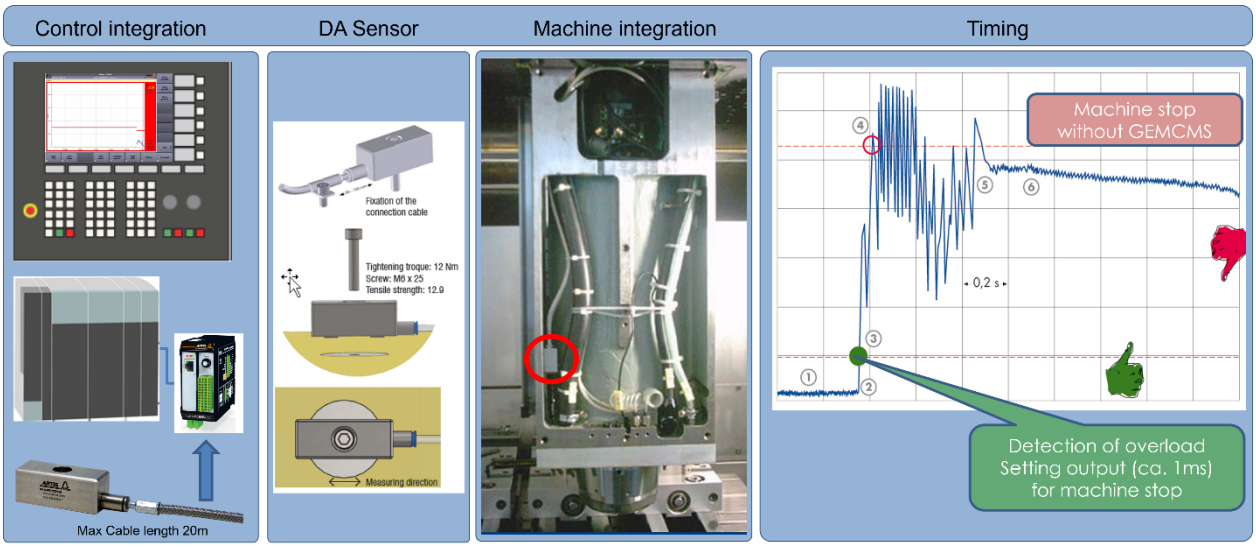
Hardware integration is horizontally scalable. On a standard DIN mounting rail, a primary CPU module can be linked to secondary software plug-ins or auxiliary sensor modules using an "In-Rail" CAN-bus connector. This allows a facility to tailor different machines for diverse tasks (e.g., combining collision avoidance with gear hobbing or adaptive control) while using the exact same base architecture.



GENIOR MODULAR - Modular System – vertical and horizontal integration

4.2 GEMCMS

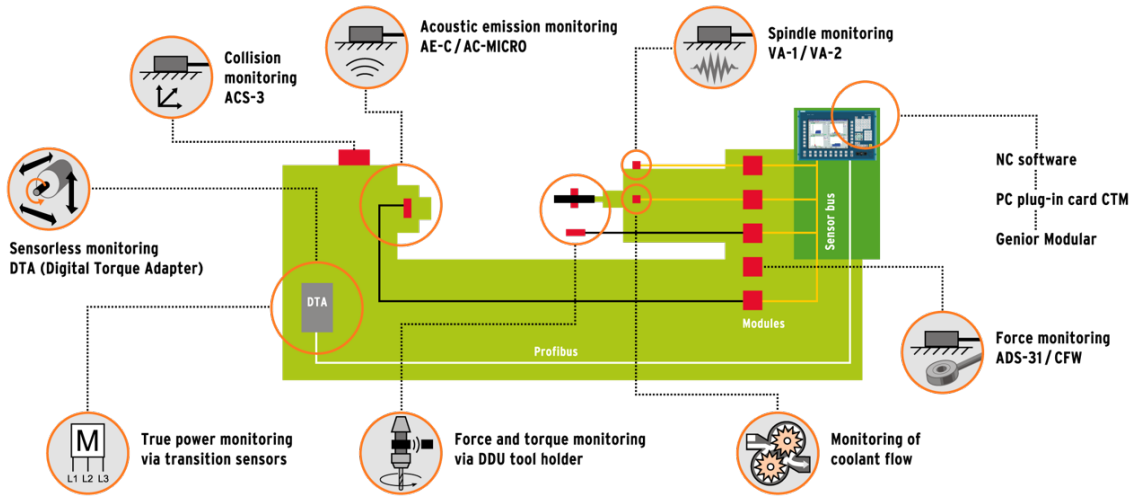
The GEM**CMS** system from ARTIS is a highly advanced, self-contained machine protection and collision detection system. It was specifically developed to prevent or reduce costly consequential damage to an absolute minimum caused by programming, setup, or operating errors on machine tools, robots, and handling systems.



GEMCMS - Machine protection with force monitoring

5. THE SENSOR MATRIX: SEAMLESS DETECTION OF ALL PHYSICAL EFFECTS

A machining process emits various physical signals. GENIOR MODULAR stands out because it can simultaneously capture and correlate the entire range of these signals using dedicated sensors and sensor modules.



Sensors in Machine Tools

5.1 ACTIVE POWER MONITORING (TRUE POWER)

Measuring the power consumption of spindle and axis motors is a cost-effective method for process monitoring. Artis systems can either read this data directly in digital form from the CNC bus or capture it as analogue signal via active power transducers (e.g. control cabinet modules). A tool breakage leads to an abrupt drop in power, while continuous wear causes power consumption to rise slowly.

5.2 TORQUE MONITORING (DIGITAL TORQUE)

Measuring the torque of spindle and axis motors is usually the most cost-effective method of process monitoring when this data is read directly in digital form from the CNC. A tool breakage typically causes a sudden drop in torque, while continuous wear causes the torque to rise slowly. The advantage of this method lies in its sensorless integration, as the data can be read directly from the NC core, for example via a so-called compile or PLC cycle.

5.3 FORCE AND STRAIN MONITORING

Using strain sensors applied directly to the spindle mount or machine bed, the GENIOR MODULAR measures mechanical deformations in the micro meter range. This enables precise monitoring of feed forces and immediately detects overloads. The technology can be strain gauge- or piezo-based, depending on the required sensitivity and measurement times.

5.4 VIBRATION MONITORING (VIBRATION / ACCELERATION)

Piezoelectric or MEMS (micro-electromechanical systems) acceleration sensors monitor the vibration behaviour of the spindle. They serve, on the one hand, to detect process-damaging chatter and, on the other hand, as a primary indicator of the spindle's condition (predictive maintenance). The used technology depends on the needed frequency range, MEMS based sensors are normally cheaper but restricted in the frequency range.

5.5 STRUCTURAL NOISE MONITORING (ACOUSTIC EMISSION – AE)

Structure-borne sound sensors detect high-frequency vibrations in the range of 50 kHz to 400 kHz, which lie far outside the human hearing range. This sensor technology is extremely sensitive and detects micro-cracking of carbide cutting edges milliseconds before the actual fracture, as well as the first physical contact between the tool and the workpiece (cutting-in monitoring). This is essential for very small tools (drills < 1 mm), where the change in active power would be too small for reliable detection.

6. PROCESS AND COLLISION MONITORING IN AUTONOMOUS OPERATION

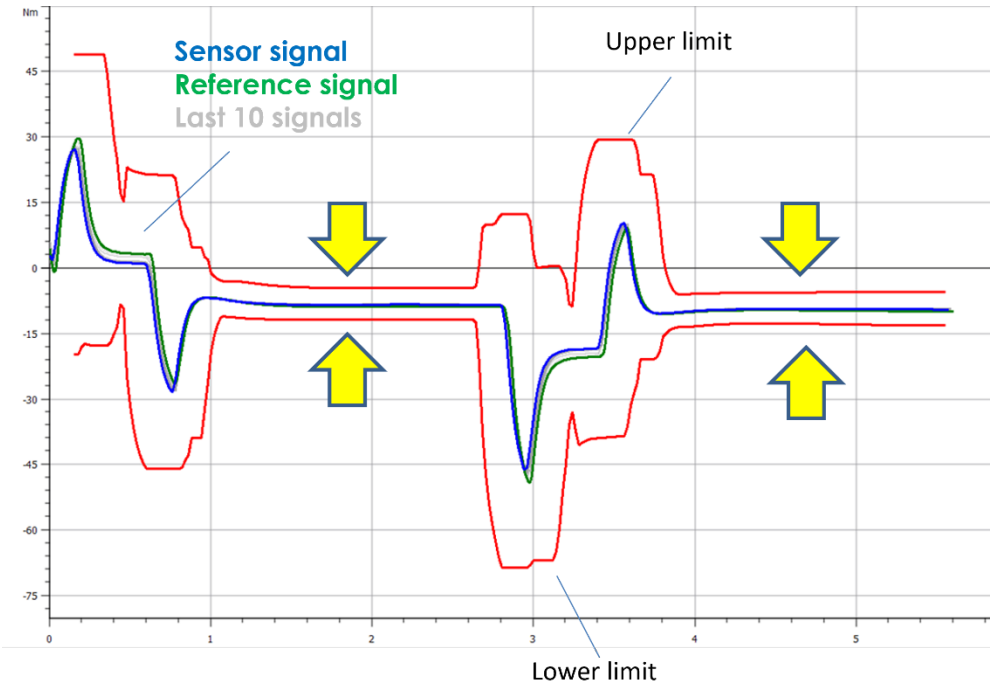
6.1 REAL-TIME COLLISION PROTECTION (ONE-MILLISECOND RESPONSE)

In the event of a collision during rapid traverse (e.g., due to incorrect zero-point offset), milliseconds count. The GEM**CMS** evaluates the signals from strain or acceleration sensors with an internal cycle time of less than 1 ms. If a defined collision threshold is exceeded, the system triggers a direct hardware interrupt to the drive controller or the emergency stop chain. The drives are actively counter-controlled or de-energized before the kinetic energy can irreparably deform the spindle bearings.

6.2 DYNAMIC ENVELOPE CURVE MONITORING IN GEM

For process monitoring, the system autonomously learns the normal signal curve of a tool during the production of the first good parts (teach-in phase). GEM automatically establishes dynamic envelopes

(warning and shutdown thresholds) around this curve.



Typical signal curve for torque [Nm]

If the upper warning threshold is exceeded due to increasing wear, GENIOR MODULAR notifies the CNC that the tool must be replaced with a sister tool after completion of the current part. If the shutdown threshold (e.g., in the event of tool breakage) is exceeded the machine stops immediately to prevent consequential damage. In addition to envelope strategies, a wide range of other algorithms is available to solve almost any monitoring task.

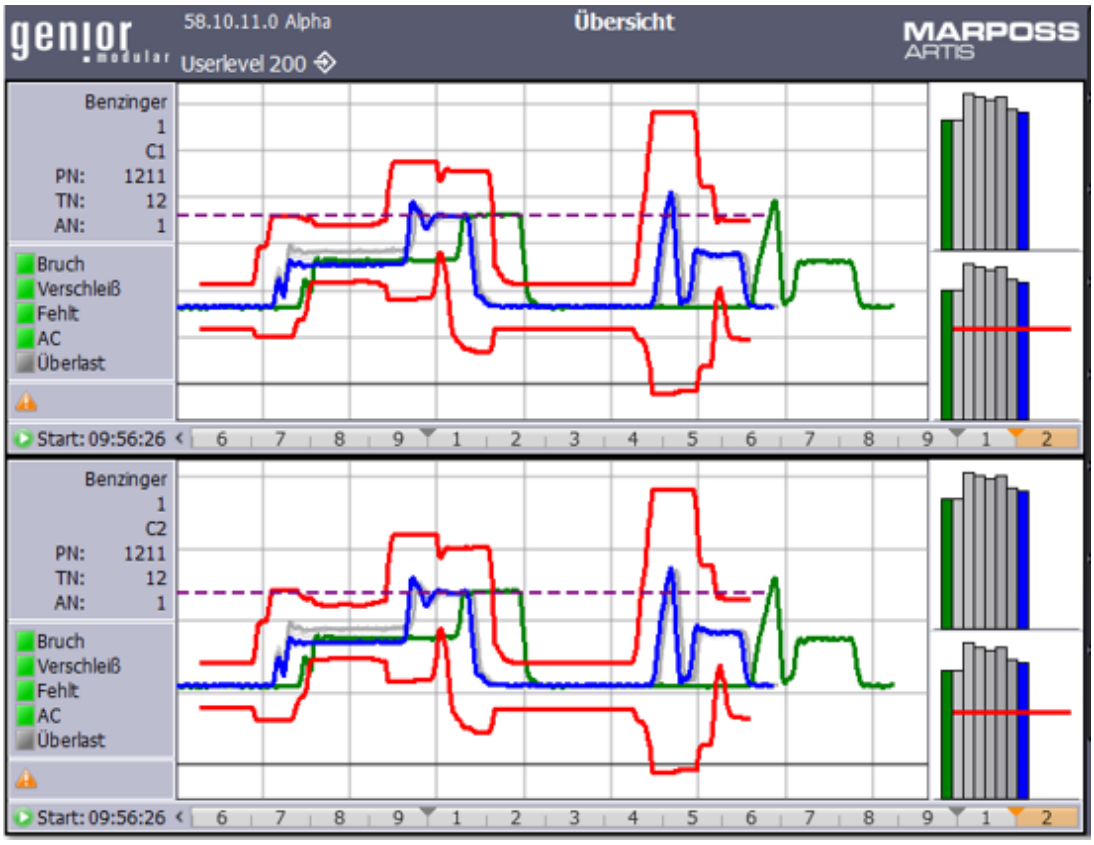
6.3 ADAPTIVE PROCESS CONTROL

In machining technology, Adaptive Control (AC) refers to systems that monitor cutting forces and machine conditions in real time. The feed rate is automatically adjusted to the material and tool wear. The abbreviation MIN here usually refers to the minimum feed rate. To prevent the machine from stopping completely when encountering particularly hard areas in the material, MIN defines the absolute minimum value that the feed rate must not fall below at any time in order to avoid tool damage. On the other hand, a MAX value defines the maximum feed rate, e.g. 130% to prevent an overload of the machine.

The innovative adaptive control in the GENIOR MODULAR (GEM) allows multiple machining stations to be regulated with regard to idle runs and insufficient or excessive cutting performance, even if they are controlled by a common feed drive. A new feature is the intelligent envelope curve adaptation simultaneously to ensure reliable and sensitive monitoring.

This allows the benefits of an AC system to be combined with optimal tool monitoring. These benefits include compensation for workpiece or material inhomogeneities, tool protection through torque or force control, automatic adjustment for tool wear, increased machining speed while maintaining consistently high quality, and improved process reliability for complex geometries. Some customers have achieved

cycle time savings of up to 10%.



2-channel adaptive control with envelope curve adaptation

7. CONDITION-BASED & PREDICTIVE MAINTENANCE IN LIGHTS-OUT OPERATION

Before starting an unmanned shift, it must be ensured that the machine can mechanically withstand the coming hours. GENIOR MODULAR enables condition-based monitoring (CBM):

Spindle climate test / imbalance analysis: An automated test cycle can be run before the shift begins. The system measures the mechanical vibrations of the spindle at various speeds. If the root mean square (RMS) values of the vibration increase over time, this indicates incipient bearing damage. The system blocks the machine from running the autonomous shift and issues a warning message.

Monitoring objective	Sensor / Module Used	Action in Lights-Out Operation
Collision protection	Piezo strain / acceleration	Immediate feed stop (<1ms) to minimize damage.
Tool breakage Tool missing Tool wear	Active power/torque (GEM) / Fieldbus	Immediate stop (<10ms) or stop after process end; request for a sister tool to the CNC control.
Micro-breakage / Start-up	Structure-borne noise (AE sensor)	Stop before the next step, eject the part.
Spindle health	Vibration module	Shut down the machine for unmanned shifts when critical values are reached.

8. BUSINESS VALUE & ROI

The investment in a Marposs Artis GENIOR MODULAR system typically pays for itself within a few months in a lights-out scenario:

- **Increased machine uptime:** Confidence in the automatic protection system allows for additional unmanned shifts on weekends, which drastically increases OEE.
- **Prevention of total losses:** The protection of a single motor spindle (often costing between $30,000 and $50,000 plus lost production) fully recoups the cost of the monitoring technology. In the case of expensive tools, such as those used in gear hobbing, costs can quickly run into several thousand euros if faults are detected too late.
- **Consistent quality:** By detecting process drift and wear in a timely manner, the production of scrap during unmanned operation is effectively reduced to zero.

9. CONCLUSION

Lights-out manufacturing poses an incalculable economic risk without intelligent, sensor-based process monitoring. The Artis **GENIOR MODULAR** system from Marposs, together with the GEMCMS collision monitoring system, provides the technological infrastructure to equip machine tools with the necessary "sensory organs." Only this deep integration of real-time protection, wear detection, and predictive maintenance makes unmanned operation a safe, highly profitable reality whilst simultaneously ensuring workpiece quality.

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Marposs was founded in 1952 and since then has provided shop-floor solutions for the quality check in the production environ-ment. Marposs' solutions include gauging equipment of mechanical components, before, during and after the production process, monitoring solutions on machine tools, assembly and testing for many industry sectors and automatic machines and checking stations for production lines.

Marposs is one of the main supplier of the major car makers, but operates as well in the aerospace, biomedical, HVAC-R, hi-tech and glass industries.

Marposs Group employs more than 3500 people around the world and is present in thirty-four countries with more than eighty sales offices.

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