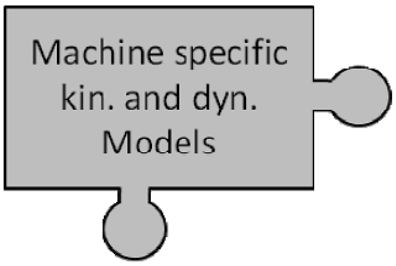
The work was supported by the EU funded project: FP7-FoF.NMP.2010-1-026621
Plug-and-produce COmponents and METhods for adaptive control of industrial robots
enabling cost effective, high precision manufacturing in factories of the future – COMET

Productive Milling with Industrial Robots

Accurate robot milling was the scope of the COMET project funded by the European Commission (www.comet-project.eu). 14 technical partners across Europe aimed to develop innovative robot machining systems that are flexible, reliable and predictable with an average of 30% cost efficiency savings in comparison to machine tools. ARTIS, 100% conducted to online process monitoring on machine tools before COMET, was involved in a work package to develop an offline approach to simulate process forces, which are considered to influence the robot accuracy behavior. ARTIS also demonstrated the benefit of the process monitoring solution Genior Modular, which safeguards the productivity level in the demo robot cell of Italian robot cell integrator SIR S.p.A., Italy.

Introduction

Entering the Computer Aided Manufacturing, CAM, technology for robots was the key for the offline improvements in the KDMIR, Kinematic and Dynamic Models for Industrial Robots, one of the 4 important puzzle pieces of COMET success story.



1. One cornerstone in COMET project success story

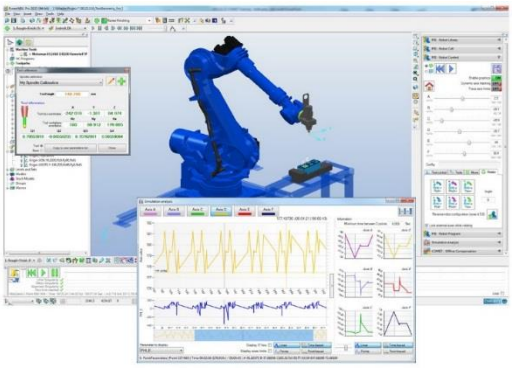
ARTIS with its broad experience in metal cutting processes did scope very soon in the work package on the measurement and the possibilities of simulating process cutting forces as an impact to the dynamic models developed by University of Lund, considering joint backlash, friction and stiffness influences.

DELCAM, CAM vendor with its product PowerMILL Robot Interface, was enabled to include process force behavior in a very early step of tool path calculations and opens a way to improve absolute accuracy in robot milling by means of offline compensation. But although major offline improvements were made, ARTIS did always point out the lack of some important information, which still needed to be monitored online, e.g. tool breakage to be comparable with a machine tool. This was demonstrated at the robot cell at system integrator SIR S.p.A., Italy, designed for advanced machining of automotive parts.

CAM - from machine tool to milling robots

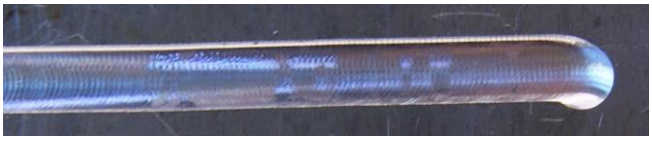
CAM was always expected to be a rich source of additional information for the process monitoring solutions produced by ARTIS before the start of the COMET project. Cutting conditions, tool engagement situation, material properties and material removal rate were still topics under development in a range of R&D projects dealing with machine tools only, the core business of ARTIS today.

ARTIS engineers joined PowerMILL for Robots training sessions at DELCAM Birmingham to learn about some new problems to be solved. Singularities, tool path deviations and work plane misalignments due to serial kinematic were three of them which needed to be encountered. Knowledge was theoretically available before project start, but solving this in a CAM suite is another challenge.



2. New PowerMILL Robot Interface 2013

It was very clear from the beginning of the project that CAM solutions for robots before COMET project were highly focused on handling applications and did not take into account the dynamic robot behavior, always being in mechanical contact with a metal workpiece. Typical robot milling test in the past did provide only poor accuracy results, see Figure 3.



3. Typical tool lead-out misbehavior before COMET

Before COMET success story this poor accuracy results gave distinction to possible robot milling accuracy.

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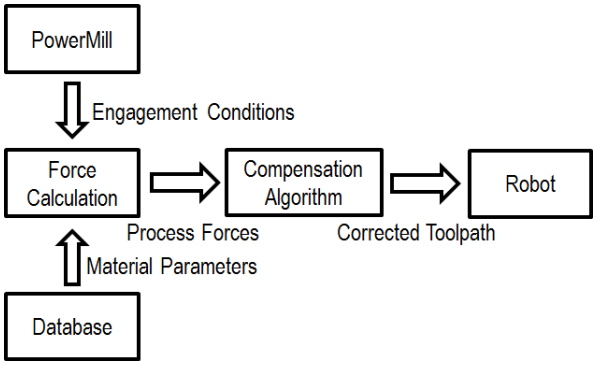
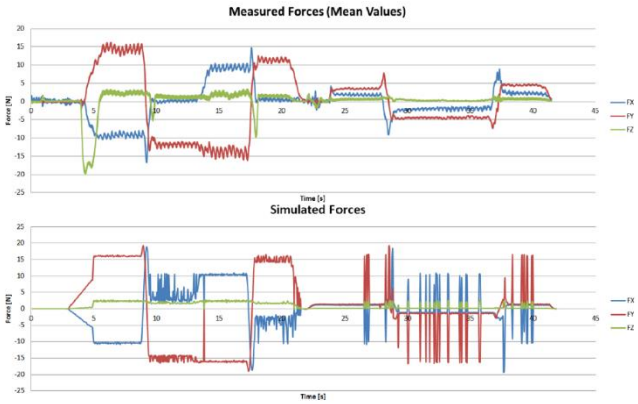
Process Forces

As the main problems robot milling are related to the process forces, the intention was to have a force calculation unit to provide input for compensation of tool path deviations in an offline approach. This part of the COMET project is called PSIR, Programming and Simulation software for Industrial Robots. The outcome of the PSIR is a corrected tool path which takes the limited stiffness of the robot into account and which lead to a better machining result. The main work of ARTIS in the COMET project was the development of the process force calculation module based on the Kienzle formula. University of Lund was responsible to develop the compensation algorithms. All these parts were then integrated into the PowerMill CAM solution from DELCAM as shown in Figure 4.



4. Offline Compensation Approach

The initial idea was to have an ideal process force model but many crucial influences like tool wear or coolant flow had not been considered in this calculation. Due to these issues there had been still deviations between simulated and measured forces up to 20% as shown in Figure 5.



5. Simulated vs. Measured Process Forces

Another problem was the lack of the required material parameters in the literature which are only available for very few materials. These issues were left open in the project and indicates further potential for future R&D projects.

Process monitoring on the SIR demo cell

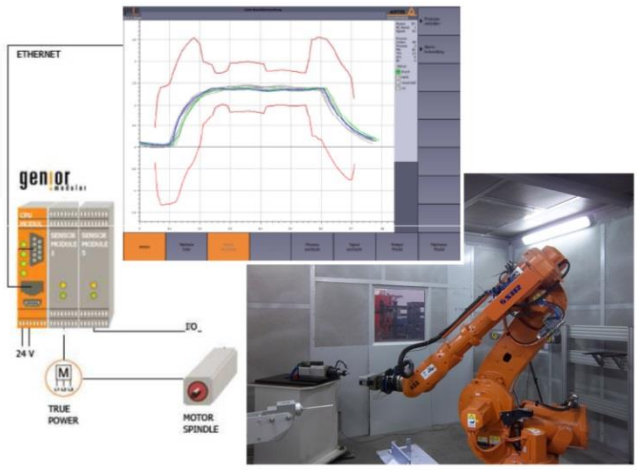
In an automated manufacturing with machine tools, the use of process monitoring systems leads to process safety. Therefore process correlating sensor signals are evaluated online. In robot milling the main automation benefits of process monitoring concerns detection of:

- tool breakage,
- tool or workpiece presence
- tool wear
- and enabling corrective actions on controller side to resume.

If a tool is worn, process forces increase. This has an influence on the machined surface, but also on the workpiece absolute accuracy. The changes in accuracy are caused by the deviation between real and simulated forces as an input for the compensation algorithm, see Figure 4. With an automatic tool change caused by a monitoring system, the process force can be held constant.

Experimental Setup

The manufacturing cell has been built up with a standard ABB industrial robot (IRB6640). In this configuration the robot moves the workpiece relative to a fixed spindle (HSD 939A). In order to receive a conclusion about the milling process, ARTIS installed the Genior Modular system to monitor the true power signal of the spindle. The system has been triggered by an I/O signal from the robot. The experimental setup is illustrated in Figure 6.



6. Experimental Setup with Genior Modular

The ARTIS Genior Modular tool and process monitoring system is fully automated and defines monitoring limits without manual configuration from the operator. To demonstrate its functionality in robot milling, slot milling processes have been prepared. Table 1 demonstrates the process parameters.

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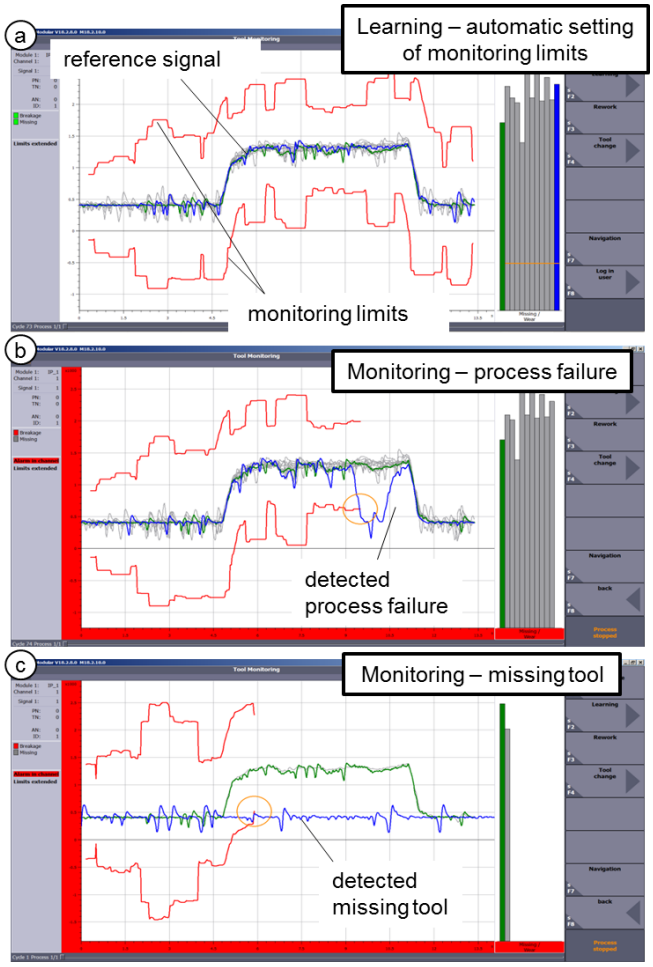
milling tool	TKN A50215 0006
milling cutter diameter [mm]	6
number of teeth [-]	4
material	aluminium
process	slot milling
rotational speed [min-1]	15.000
feeding rate [mm/s]	10
cutting depth [mm]	3

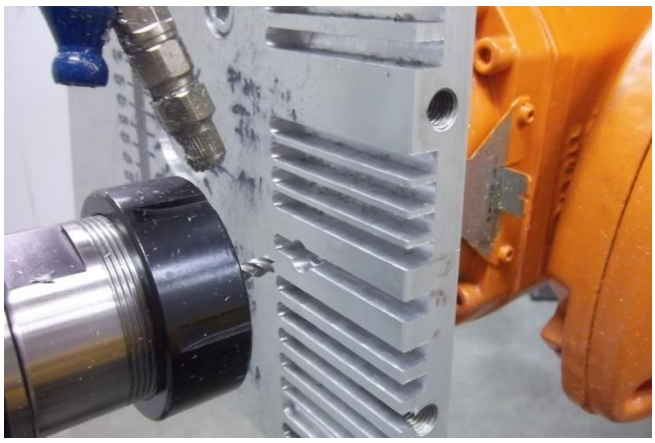
Table 1. Process parameters

The results of monitoring the slot milling processes with Genior Modular are illustrated in Figure 7. In Figure 7a the reference signals of a correct running process are depicted. The system uses these processes to determine all parameters for the monitoring limits. With the help of the sensitive, trained system, processes were monitored which include provoked process failures.



7. Online process monitoring screenshots

One process error has been simulated by a hole in the tool path. Figure 7b shows a drop in the true power signal caused by a decrease of the process. This process failure has been detected by Genior Modular. The monitoring behavior can also be regarded as an example for monitoring tool breakage, where the monitored signal crosses the upper or lower limit. The case of a missing tool was regarded in Figure 7c. Again, the abnormal signal characteristic has been automatically detected by Genior Modular.



8. Milling slots and the fake hole to simulate a process error

Conclusion

Calibration and joint-based model with integrated process force simulation have been the most important offline result in this project. In other words, more available offline information into tool path calculation improved absolute accuracy during robot milling in a high manner in eight demo robot cells. This encouraging message to all (new) robot owners was confirmed by the EC in the final project meeting.

This directly leads to the question, which information is not available offline and how to solve this problem in the scope of daily production.

Ensuring tool presence is one of the core questions to future users of the COMET results in robot milling. By this the demand on adaptive solutions for automated tool change, like ARTIS Genior Modular, will increase to safeguard cost savings and productivity.

ARTIS started to continue this road in the national funded R&D project INNOFLEX with an important structural component supplier for aerospace industries as lead user. This will shift TRL, Technology Readiness Level, for robot milling technology into new dimensions.

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