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FORCE-TORQUE CONTROL METHODS FOR INDUSTRIAL ROBOTS

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Abstract: *The paper deals with Force – Torque control methods for industrial robots. The key aspect of these methods is to control a contact between a tool and a workpiece when either the tool or the workpiece is mounted on the robot flange. Real-time control of contact forces and moments is necessary. It is suitable to use it on a variety of industrial operations such as grinding, deburring, other machining operations or automatic assembly. The experimental set-up is based on a KUKA robot with FTC sensor (SCHUNK FTC-050) mounted on the robot and an external PLC system used for main control and connecting other essential sensors and devices. Main practical results are concerned with a design of specific end effector for a specific workpiece and with determining the contact between a workpiece and the surface maintaining a constant force during robot motion.*

Keywords: ***Force-torque control, industrial robots, real-time control, PLC, robot motion***

1. Introduction

Industrial robots programming is still a difficult and annoying task and expert knowledge is necessary in most cases. Due to this disadvantage the industrial robots are mainly used in fixed installations and they are used for repeatable tasks and programmed by an expert.

One of the greatest limitations and also one of the greatest space for further research represent a robot interaction with the worker. In many cases, it would be useful alow this interaction and it can help with robots integration to new industry fields. Nowadays the worker and the robot are usually separated trough some type of safety system.

Other important space for further research is in a need to automate the applications that are nonstandard for robots. Need to control the contact forces and moments between the robot and its environment is essential for this type of operations to ensure a right task performance. One of the representatives of this field are finishing operations (Boque, 2009; Pires, et al., 2002) like grinding, polishing, deburring, etc.

The next demand is concerned with a new robot programming technique that is based on human robot interaction and cooperation. Needles, to say that safety is the biggest task for this approach, because the robot workspace is fully shared with the worker. This technique allows the tasks to be frequently and easily changed and robots can be programmed online by demonstration of non-expert.

To use a robotic cell for finishing operation or human robot interaction, there is a need to ensure right force-torque feedback based on a force-torque sensor (Perry, 2002). Various control architectures can be applied (Bigras et al., 2007; Blomdell et al., 2005; Caccavale et al., 2005). The best way would be a force controller based on the complete model of the robot. Due to closed architecture of the robots that rarely allows a direct control of motor torque, this type of controller is difficult to implement on the actual range of industrial robots. Due to this fact, in this project we applied a cascade force controller even though we know that it does not take into account the whole model of the robot and only a tool position can be controlled.

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2. Industrial demands

This project of force-torque control of industrial robots is motivated by real industrial demands. In collaboration with our industrial partner Blumenbecker Prag s.r.o. we received various components for testing and currently we are dealing mainly with components intended for finishing operations.

To answer the needs, the project have been initiated (we successfully asked for funding – Ministry of Industry and Trade of the Czech Republic) and we established a research platform based on academic-industry partnership.

Specific workpiece for grinding and deburring from our industrial partner is shown in Fig. 1, it is a coupling for chains. Surfaces that must be manufactured are shown in yellow in Fig. 2.

Fig. 1. A component example

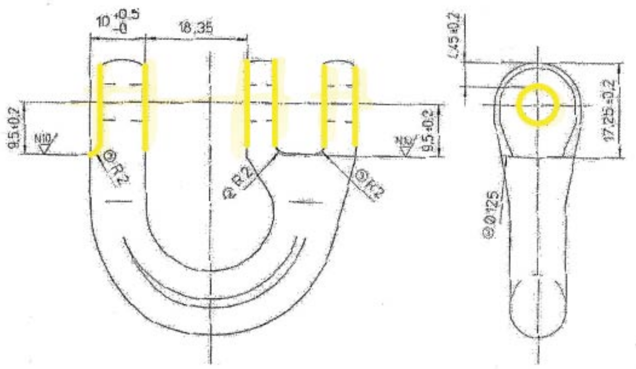

Fig. 2. Surfaces for manufacturing

As be seen from figure 1, this component is hard to be grasp by conventional end effector with simple parallel jaws and more specific and complicated procedure had to been used for this workpiece.

3. Design of the end effector

A basic principle of object grasping is presented in the following Fig. 3. A 2-finger parallel gripper equipped with angled prismatic inserts (parts 1 and 2) is used to grasp the component. As additional supporting element, a pneumatic cylinder (part 3) is used to hold the component using another prismatic element.

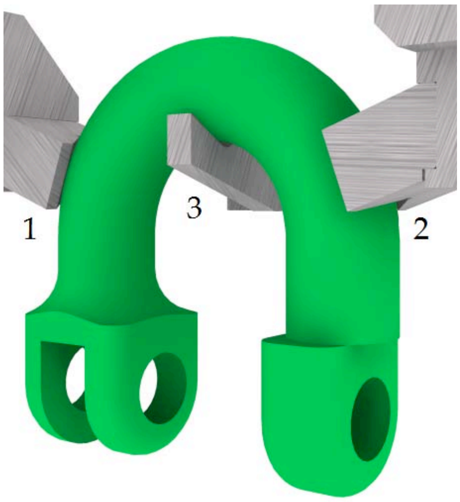

Fig. 3. A basic principle of object grasping

The described principle have some difficulties, a part is actually forced out by parallel jaws during pressing process. This force is reduced by selecting a proper tilt angle of prismatic inserts and by supporting pneumatic cylinder called “nose”. A suitable material, with sufficient friction coefficient, need to be used for prismatic inserts. However, details concerned with this procedure are not covered in this contribution.

From the beginning the idea was to create the end effector to grasp all components from the whole production range of chain couplings and various alternatives of the end effector have been designed. Mainly due to large weight of the end effector it was decided to produce a device for grasping limited production range. Final design of the end effector is shown in Fig. 4.

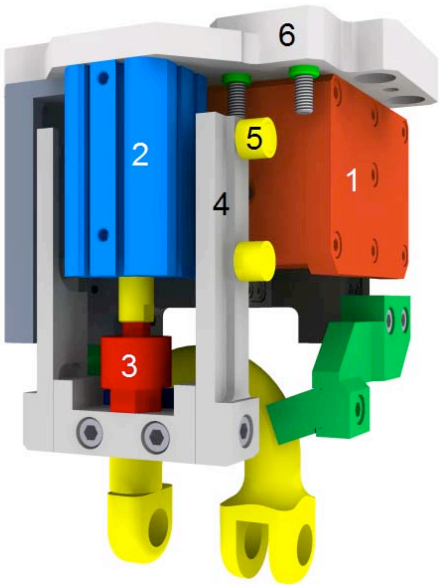

Fig. 4. A model of the end effector

4. Control methodology

The following figure shows the hardware structure of robotic cell (Fig. 5). Data from the force-torque sensor (SCHUNK FTC-50) is sent to the PLC (Embedded PC Beckhoff) via serial connection RS232. Information about the contact force and torques are processed in the PLC and control deviation is processed here too. Control deviation is sending to the robot controller via DeviceNet interface. In the robot controller KUKA RSI (Robot Sensor Interface) is used to fulfill the condition of real-time data processing, it is a software package for communication with sensors and other devices in defined 12ms cycle.

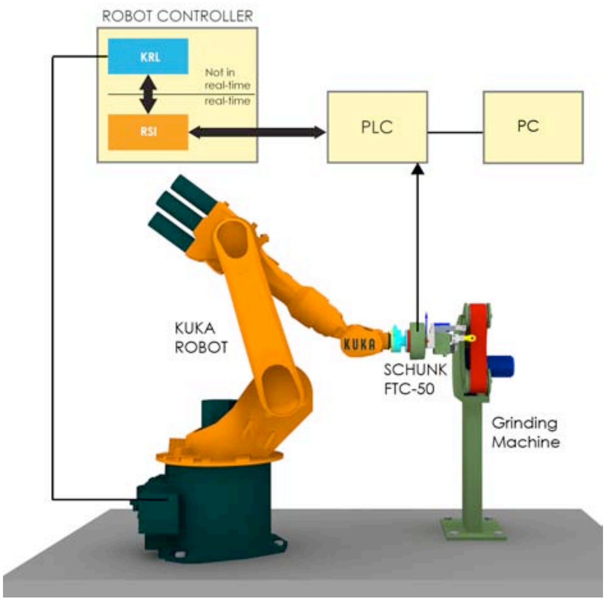

Fig. 5. Main structure of the robotic cell with general control structure

The following figure shows block diagram of control system (Fig. 6). Data from force torque sensor is processed by the gravity compensation block (f_{cont}) than it is compared with desired force (f_{des}) and after that it is processed by a couple of the PID controller (Reg I and Reg II). First of them is used for greater deviation on the beginning of the contact. Second of them is used for smaller deviation.

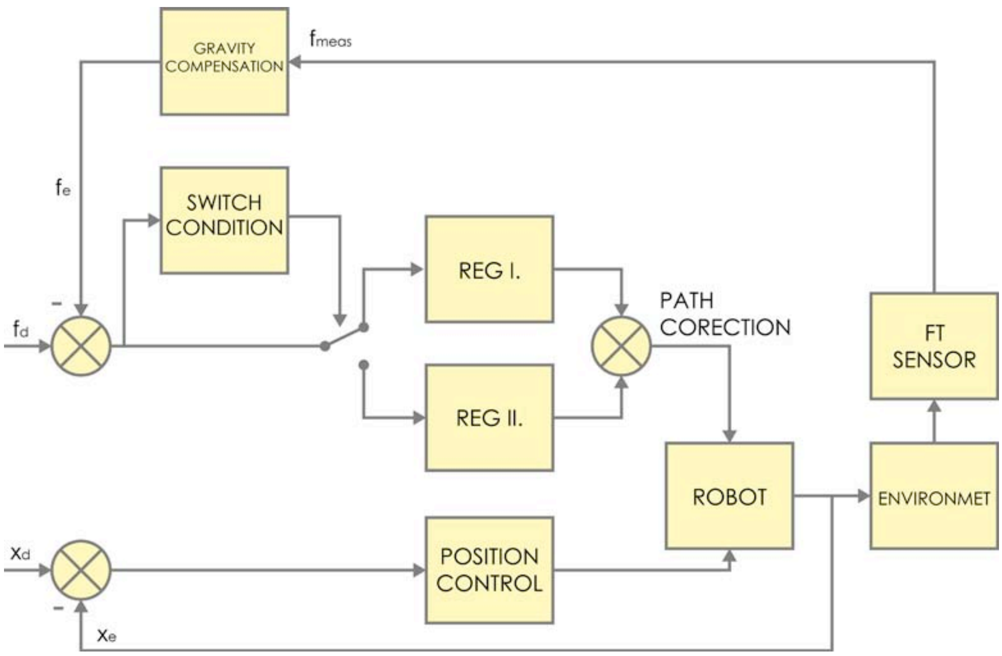

Fig. 6. Main block diagram of control structure

5. Machinery stiffness

For more accurate regulators constants adjustments some experimental measurements of used machinery stiffness have been made. Measurements was made on belt grinding machine and universal grinding machine Protool. Force torque sensor mounted on the flange of the industrial robot and the end effector with grasped object was used for push against the grinder. Amount of contact force was measured by force torque sensor and position (grinder deflection) was measured by the robot control system (Fig. 7).

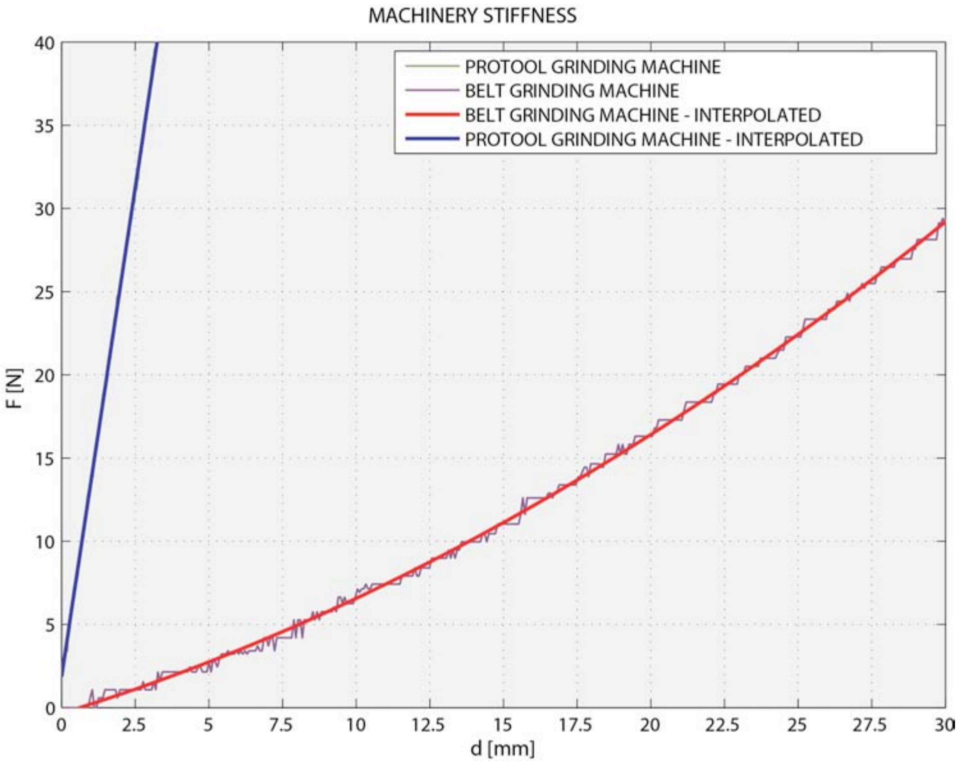

Fig. 7. Measurements of used machinery stiffness

A important advantage of this method for measure stiffness is that it is take into account stiffness of all parts (robot, sensor, end effector, grinders) due to this, data shown in figure reflect stiffness of all parts in kinematic chain. It is essential for proper control adjustment.

6. Results

Finally we present pilot results of the force-torque control based on the control structure described above. The following Fig. 8 shows example of time behavior of the contact force.

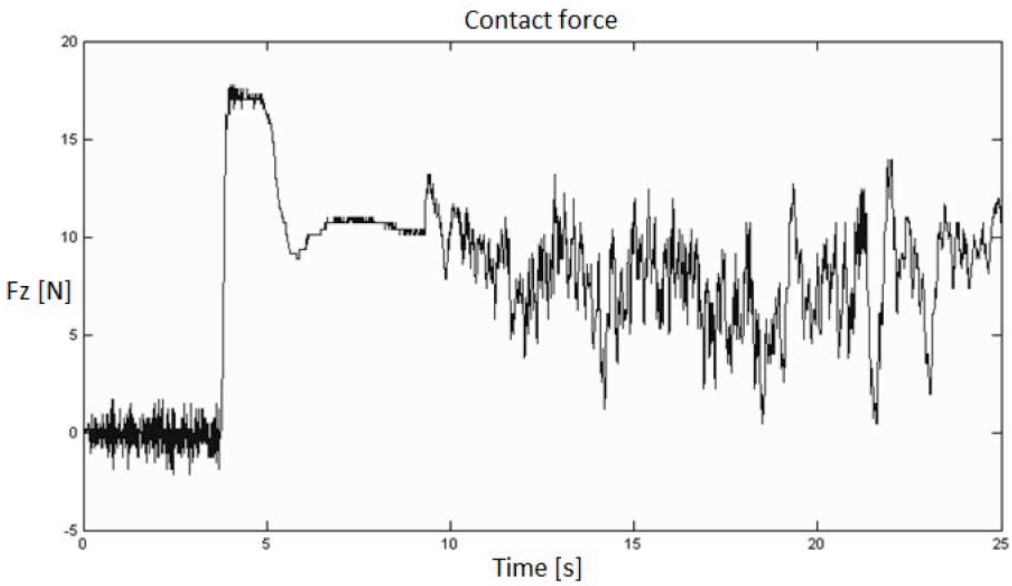

Fig. 8. Contact force during the robot motion along the surface

The desired contact force to maintain while the robot is in contact with the surface is set to 10N. The big increase in strength on 4 seconds is for first contact between robot an its environment (grinding machine). The interval between 6 and 9 seconds is for maintaining the contact force on a single robot position and interval after that is for maintain the constant contact force during robot motion. As can be seen the robot gaining and losing the contact during motion and the process need to be further optimized and this will be the main part of our future work.

7. Conclusion

Pilot results were presented using the control architecture described above where a desired contact force with object surface can be controlled allowing the robot follow object profiles.

All data processing and control algorithms is processed in the external PLC system (Embedded PC Beckhoff. Due to this, the control is independent on robot controller, it is important advantage of described control architecture. The only condition for KUKA robot controller is in need of RSI (Robot Sensor Interface) software package to be installed to fulfill the condition of real-time data processing.

Acknowledgement

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