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MONITORING AND TESTING END-EFFECTORS FOR ROBOTS

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Abstract: When using robots in automated production it is necessary to use different end-effectors (grippers, tools, measuring units) built in the last robot wrist for handling, welding, machining, assembling, etc. the workpieces. The end-effector is one of the main parts of the robot, which connects the robot with the working environment and gives the possibility to make manufacturing more flexible. It is necessary to replace the manned inspection with sensors to increase the quality of the products and the reliability of the robotized operations. To eliminate the disturbances during monitoring the sensors give information about the end-effector to the robot control. The end-effectors should be tested either after the development of prototypes or before their selection for application. The measuring test gives the most important technical data about the end-effectors, such as position accuracy, static and dynamic stiffness, load capacity, etc., which show whether they are suitable for the given tasks, operations or not. The authors give a short overview about the grasping force monitoring of the grippers, the monitoring of end-effectors using a 6D-force-torque sensor built in the last robot wrist and the measuring tests of an end-effector changer and a RCC-unit.
Keywords: monitoring, testing, end-effector

1 INTRODUCTION

Monitoring and measuring tests are tools to increase the quality and the reliability of the robotized production. The applied contact and non-contact sensors give information about the operations and processes. The simple (proximity) sensors and the more intelligent (force/torque) sensors (multi sensor system) built in the end-effectors make possible to increase the adaptivity, flexibility and reliability of the robots. The test helps to determine the most important technical data of the end-effectors, which show whether they can realise the tasks described in the documentation or not (selection and qualifying of end-effectors).

2 THE ROLE OF END-EFFECTORS IN THE ROBOTIZED PRODUCTION

There are many different operations in the automated manufacturing, which can be realised by using robots. These operations are handling, welding, measuring, assembly, painting, paletting, deburing, etc. During the operations many end-effectors have to be used, which are built in the last robot wrist. They are grippers, tools for peg in hole operations, screw tightening, gluing, welding, and pressing, riveting, measuring and other special operations. They are stored in magazines. Before and after the operations the end-effectors can be changed by using a changer [1,3].

3 MONITORING THE END-EFFECTORS

The monitoring of all operations including the changing operations helps to increase the reliability of the assembly process and the quality of products. One part of the monitoring tasks can be realised by using different proximity sensors, which give binary signals, detecting the position or status of the tools or elements of the tools: e.g. if they are open or closed, etc. But there are more complicated (intelligent) monitoring tasks, as well. Among the others grasping force monitoring, monitoring of actual pressure of pneumatic grippers and tools, force and torque monitoring for different operations using 6D force-torque sensors built in the last robot wrist [1,5].

3.1 Grasping force monitoring

In some applications the direct control of the robot gripping force is unavoidable, for example in the case of deformable workpieces or when the surface quality of the workpiece is strictly defined or when the safety of handling of work pieces needs limited grasping force. Two different methods were carried out for measuring the gripping force during assembly [1,2].

One way is to place an external force sensor in the robot's environment. In this case the robot has to grasp this force sensor from time to time to check the actual grasping force (pre-process measurement). When it is between the given limits, then the robot continues the operation.

The other way is to make possible the continuous monitoring of the gripping force during the assembly (in-process measurement). In our experiments a Puma-760 type robot equipped with a special gripper was used. To measure the force in the robot finger, a strain gauge force sensor was integrated into the finger, which was developed by us in co-operation with KALIBER Ltd, Budapest. During the design of the finger several stress-optic tests were made to find the size location and orientation of the main stresses. Figure 1 shows this sensorised gripper. Two special PC cards (PCLD-770 and PCL-711S) were applied for data acquisition and signal processing, so the cell controller software could directly read the measured force data [2].

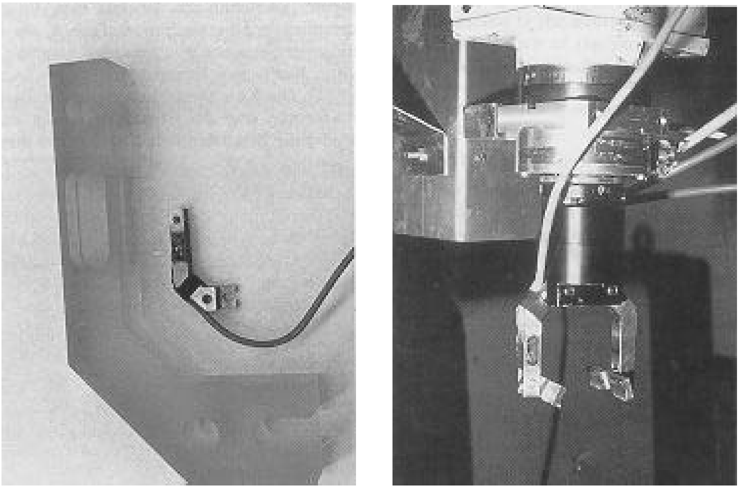

Figure 1. Measuring finger, its plastic model (left) and the gripper with measuring finger and 6-axis f/t sensor mounted into the last robot wrist

The control of the gripping force of the pneumatic robot gripper could be realised by controlling the air pressure of the gripper. The air pressure could be controlled only in discrete steps (0.5 bar) instead of continuous control, because it was satisfactory in this case. The actual air pressure values can be activated by robot control through its Output channels using special pneumatic units with predefined, adjusted air pressure values from 3 to 6 bars. The actual pressure value should be monitored by using pressure sensor based on strain gauge technique. The sensor gives information to the robot control about the pressure value.

The main technical data of the sensorised gripper are:

- measuring range: F= 40–70 N (air pressure: 6 bar),
- stroke of the gripper s= 40 mm (from 30 to 70 mm).

The gripper can be used for handling of disc type workpieces.

3.2 Force-torque monitoring with 6 axis force/torque sensors built in the end-effector

We solved several assembly tasks using a 6-axis f/t sensor in our assembly cell. The sensor was built between the end-effector and the last robot wrist. We applied the f/t sensor for monitoring the technological forces and torques reacting during the assembly process. A special hardware ("Miniforce") and software were applied for data acquisition and signal processing [1,5].

During ball-tap assembling processes at the TU Budapest two vision-modules and one 6-axis f/t sensor were used. The f/t sensor was mounted into the last robot wrist (Figure 1.).

The applied six-axis f/t sensor system was primarily developed for Open Robot Controllers with bus-level interfacing possibilities for external sensors. The sensor system consists of three main parts: the 6-axis f/t sensor, the signal-processing unit and the interface unit.

The 6-axis f/t sensor is a device used for measuring f/t vectors at any selected points of the space in terms of their x, y, z axes in a Cartesian co-ordinate system. The sensor operates on tensiometric principle having a special metal body on which strain gauges are placed at adequate points. The construction of the sensor results a very compact device, exceptionally good repeatability, small deformation and small cross-sensitivity.

The main technical data of applied 6-axis f/t sensor type TARA SCT-02-A (Fig. 1):

- Measuring range: Fx: 50 N, Fy, Fz: 100 N; Mx: 2 Nm, My, Mz: 5 Nm
- Linearity: 0.1%; Repeatability: 0.1%; Overload: 500%; Size: Ø 80x30 mm; Mass: 0.4 kg.

The most important technical data of signal processing unit (Fig. 2):

- Input signal: min. +8V max.+ 12V DC/1,5 A; Output: RS 242A/RS 423 A (300-3800 baud).

The most important technical data of Miniforce Interface unit:

- Input signal: 220 V AC; Output: RS 423 A (300-3800 baud), RS 232 C (300-9600 baud).

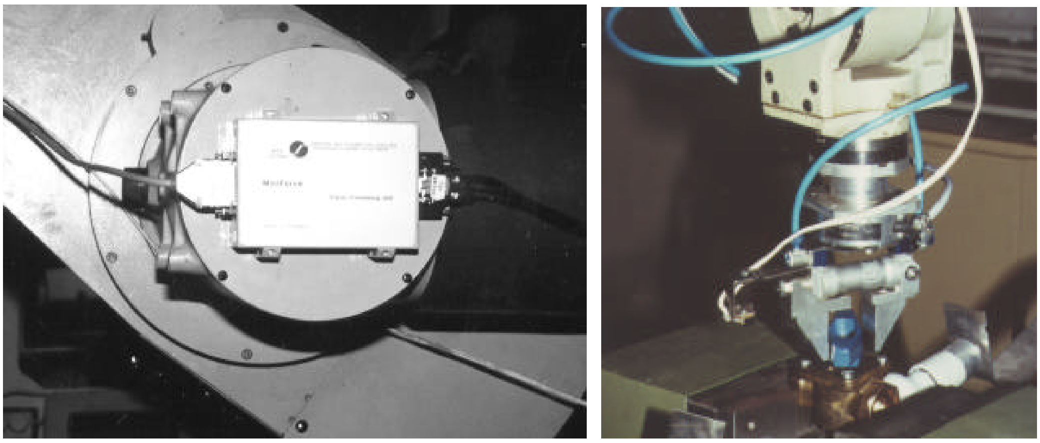

Figure 2. Signal processing unit (left) and the 6-axis f/t sensor monitoring the torque (functional test)

The signal-processing unit was mounted on the robot arm. This device and the torque limited rotating of assembled ball tap (functional test) by using 6-axis f/t sensor are shown on the Fig. 2.

4 MEASURING TEST OF END-EFFECTORS

The test and the measurement of the main technical data of end-effectors and fixtures are very important tasks to realise the increasing flexibility and reliability of the robotized operations and to improve the quality of work pieces. The measuring test gives important technical data about the end-effectors, such as position accuracy, static and dynamic stiffness, load capacity, etc.),

4.1 Test of an end-effector changer

After development of a prototype or before selection for application the end-effectors and the fixtures should be tested and the most important technical data, (mechanical quantities) should be measured, for example:

- position and orientation accuracy, position repeatability,
- static and dynamic stiffness,
- coupling, uncoupling and clamping forces,
- exchange time,
- load characteristics, etc.

There are two ways to test and to supervise them:

- testing the end-effector in special testing devices (in general for prototype only),
- testing the end-effector built in the last wrist of a robot (for application only: complex test).

In the first case testing devices can only test the characteristics of end-effectors and fixtures. The second testing method is a complex test for robots with end-effectors. It gives information mainly for users (whether the end-effectors may or may not be applied).

In this paper the authors will introduce the testing methods and results of an end-effector exchanger and a RCC (Remote Compliance Centre) unit. When the load capacity of the robot does not allow the aapplication of a multi-function end-effector system, then an end-effector exchanger must be applied to change different grippers and tools. We tested a changer (load capacity: 10 kg) developed by TU Budapest as a prototype [3,4].

During testing the following important quantities were measured:

- position accuracy,
- static and dynamic stiffness.

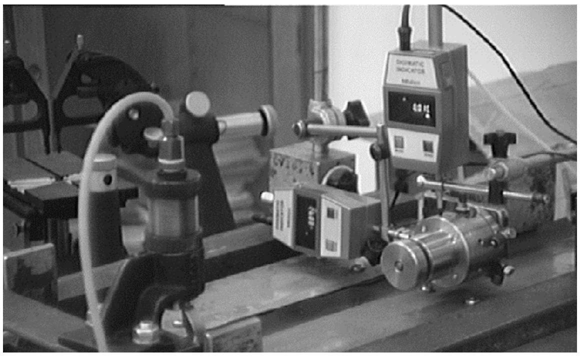

Figure 3. Measuring device for testing position accuracy

For measuring the positioning accuracy we have built a testing device which is able to measure the difference between the start position and the actual position in X and Y directions with two linear incremental gauges (measuring range: 10 mm, resolution: 1 ìm). The actual X and Y values have to be measured after all changing operations using a cylindrical gauge. Figure 3 shows the testing device. We have repeated the changing and measuring fifty times and have made the statistical processing of the measurement data.

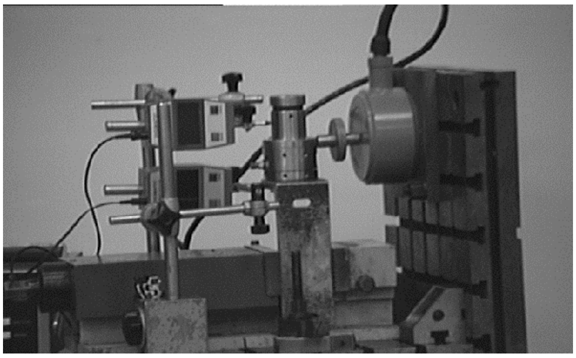

Figure 4. Measuring set up for testing static stiffness

When testing the static stiffness the deformation due to force should be measured. Figure 4 shows the measuring device. The different force values were transmitted and measured by a force sensor (measuring range: 100 N) based on strain gauge and the deformations (in X and Y directions) were measured by two linear incremental gauges.

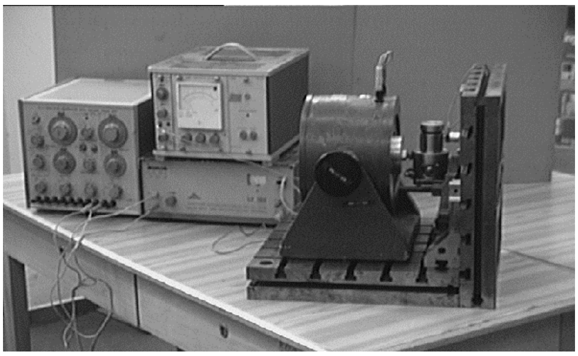

Figure 5. Testing the dynamic behaviour of the changer

The resonance frequencies in two directions were measured for determining the dynamic behaviour of the changer. Figure 5 shows the testing station, which consists of a low-frequency generator (f = 0.01–1100 Hz), an amplifier, a harmonic excitation device and a vibrometer with two piezoelectric sensors [3,4].

Table 1. Measurement results of the testing an end-effector changer

Direction	Positioning accuracy (µm)	Static stiffness (N/mm)	Resonance frequency f1 (Hz)	Resonance frequency f2 (Hz)	Resonance frequency f3 (Hz)
X	<± 13	3221	189	725	1043
Y	<± 15	451	131	242	908

The amplitude values of vibration were measured at different excitation frequencies. In the Table 1 we show the average measurement results.

4.2 Measuring test of a RCC-Unit

The Remote Compliance Centres (RCCs) help to eliminate the disturbances caused by the positioning accuracy of the robot while inserting peg in hole. As the second example the measuring test of a RCC unit is introduced here. Fig. 6 shows this robot periphery and the Table 2 summarises the main average parameters of the three different geometrical configurations.

Figure 6. The investigated RCC unit

The aim of the stiffness measurements was to check the data of the RCC device given by the manufacturer in users' manual. A peg fixed to the RCC device was loaded in radial direction with the help of a one-axis force sensor based on strain gauge technique (measuring range: 100 N) and thedeformation of the peg was measured by a linear incremental gauge (measuring range: 10 mm, resolution: 1 ìm).

Table 2. The main parameters of the selected RCC device

RCC-type	Product Number	Stiffness			L_0 [mm]
		Displacement [N/mm]	Bend [Nm/rad]	Torsion [Nm/rad]	
111A	320 300	12	350	5.7	98
111B	320 301	11	380	7.8	118
111C	320 302	23	660	13.6	108
Maximum compensation					
Displacement		Bend		Torsion	
±2.2 mm		1.1°		5°	

While loading the peg the load capacity of the RCC device was taken into consideration as follows:

Table 3. Load capacity of RCC unit

type 111A	Type 111B	type 111C
9 N	9 N	18 N

After carrying out loading cycles the obtained results show non-linearity and a significant hysteresis in the force-deformation function of the RCC device. Therefore the static stiffness factors of the RCC device are not constant values and they also depend on the load direction. (as an example see Figure 7).

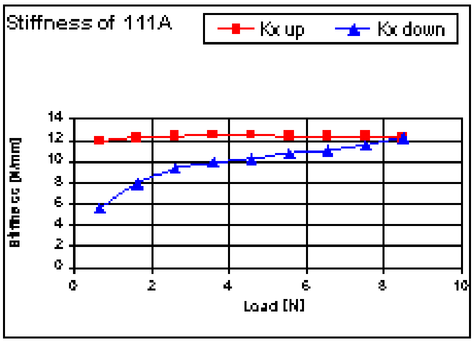

Figure 7. Static stiffness-load function of RCC Type 111A

The other purpose of the measurement was to determine the dynamic properties (damping and natural frequencies) of the RCC device. During the measurement two sorts of excitation were applied: pulse excitation in order to specify the damping coefficients and harmonic excitation in order to specify the natural frequencies of the system (this second test was carried out by the same hardware like the investigation of end-effector exchanger).

In order to determine the damping coefficient the damped vibration of the peg caused by the unit pulse excitation was measured with the help of two non-contact inductive sensors. The signals to be analysed were gathered by a digital storage oscilloscope through a carrier amplifier. The signal processing was carried out by means of a PC-386.

5 CONCLUSIONS

The test and the measurement of the main technical data of end-effectors and fixtures are very important tasks to increase the flexibility and reliability of the robotized operations and to improve the quality of work pieces in the small and medium size production.

The paper introduced 2 tests, which were carried out at the TU Budapest. The first periphery (end-effector exchanger) was applied in a robotized station for assembly of different parts. The second one (RCC unit) will be applied to realise "peg in hole" tasks in robotized assembly. Before application the end-effectors built in the last wrist of the given robot must be tested. The results of the complex test will show, whether they can be applied for the given task or not.

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