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IML ROBOT GRASPING PROCESS IMPROVEMENT*

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Abstract– This paper presents an example of how a differential pressure sensor can be used to improve grasping of in-mold-labelling (IML) robots. In order to minimize mold-open time on injection molding machines, shorter operation time is desirable. To achieve this goal, an analysis of grasping labels using the in-mold-labelling robots was done with different approaches to improving the grasping process by measuring pressure in the chambers of the cylinder which carries the tool for grasping labels. The approach that uses the differential pressure sensor has proved best.

Keywords– IML robot, grasping, pneumatics

1. INTRODUCTION

There is a strong competition among manufacturers to comply with everyday changes on the market. Accordingly, an effective product design of plastic molding used for promotional purposes is becoming more and more important. The in-mold-labelling (IML) process is the ideal alternative for secondary operations, such as the subsequent printing and various other applications ranging from technical devices to food packaging. Also, in the case of food packaging, the primary motive for resorting to IML is a more appealing product design, bar codes and product information on the packaging required by law.

IML is the technology in which molded plastic items are being labeled before they are formed [1-2]. Those labels are fetched into the mold of plastic injection molding machines (IMM) with different kinds of robots or manipulators [3]. Such labels serve as the integral part of the final product, which is then delivered as a pre-decorated item [4]. Any manufacturer that uses IMM, requires machines capable of achieving a shorter mold cycle time, meaning that the time requires shorter post-molding processes. The key point is to position labels into the mold quickly and accurately between each mold cycle and removal of parts, after the injection process has been finished. This applies to both the IML technology and post-molding processes. One of the recent trends in the IML technology is to use the same robot to insert the labels and to extract the finished parts, which involves elimination of subsequent processing steps and shortering the post-molding cycle time. In this way, subsequent processing steps are eliminated and the post-molding cycle time is shortened.

The IML robot can perform label grasping only when it has an adequate gripper or tool. It also requires choosing the appropriate methods of label grasping and handling. Designing such a gripper or tool requires knowledge of several interrelated subjects [5] including the gripper and tool design (according to its label type), force, position, compliance control [6-7] and quality of air preparation [8]. Furthermore, the in-depth quality control of such a process is essential and can be accomplished by the

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machine vision system [9]. This system can also contribute to fault diagnostics needed for both economical and operating reasons [10].

The common feature of IML robot structures is that they use vacuum technology for label grasping, thus the gripper and tool are equipped with a vacuum suction cup or cups. In most cases, the gripper or tool is moving, and is carried by a pneumatic actuator. In order to achieve a faster post-molding cycle, the key point is to find the best control method for the pneumatic actuator. Economical, as well as technological reasons require robot systems with improved efficiency [11]. This paper presents the solution which is based on measuring the pressure in the chambers of the pneumatic actuator, aimed at improving the grasping process on IML robots. This results in a more efficient IML product fabrication.

2. PNEUMATIC ACTUATORS IN IML ROBOTS

Pneumatics is one of the basic technologies that has been used over generations for linear pneumatic actuators. There are several advantages of pneumatic actuators, such as simple speed adjustability, overload proof without energy consumption for retention forces, high vibration resistance and low maintenance throughout their entire service life. They are also almost ideal for application in continuous systems. Pneumatic actuators are used on IML robots in several cases, ranging from the robots that are fully pneumatic, to the most frequent case of carrying the gripper or tool for the label grasping. Pneumatic actuators can enable support for a gripper or tool, which is used for label grasping. This method is cost effective because of the requirements of IML production processes. Those conditions require constant modifications due to the constant changes in product demand. The typical design of the gripper, the label or tool for label grasping is illustrated in Fig. 1.

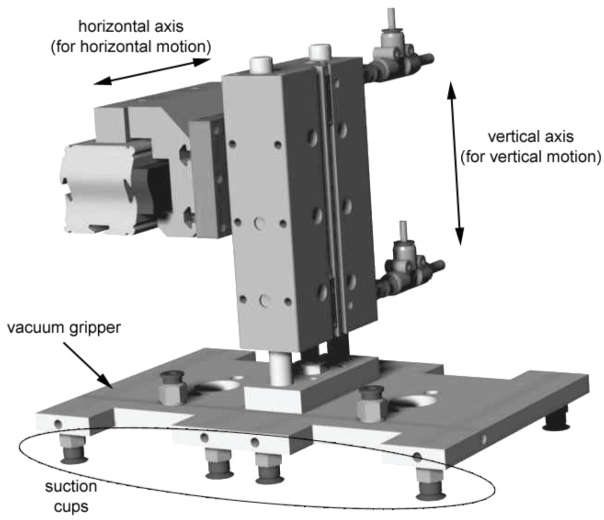


Fig. 1. Typical gripper or tool design used for IML robots for the label grasping

The gripper or tool is designed to grasp and hold labels during the molding process. They can be used during the preparation of a new plastic product for production. The label shape and dimensions will determine the gripper or tool type and design. The gripper or tool should satisfy the following basic requirements: reliable label grasping and holding the label during transportation, especially during acceleration and stopping when the label is captured and impacted by inertial machine loads. In order to optimize the control of the gripper/tool, it is very important that the device is equipped with feedback sensors. They are used to provide data related to labelling pick-up and drop-off. These sensors can be divided into two categories, based on their (1) grasping force and (2) position. These different categories use a common control strategy.

The grasping force required to hold the label may be calculated using the following formula [12-14]:

$$F_g = mgK_1K_2K_3 \tag{1}$$

where

m - Mass of the label;

g – Free fall acceleration;

K_1 - Safety factor, its value depends on the conditions during its application (K_1=1.2...2.0);

K_2 – Factor which depends on a peak acceleration, and occurs when the IML robot moves the gripper/tool (K_2=2 for the pneumatic industrial robot); and

K_3 – Factor which depends on a gripper/tool construction (K_3=0.5 ... 4).

In the case of the IML robot, the gripper/tool uses the vacuum system to grasp and hold the label. Based on this, the grasping force F_g from (1) can be calculated as the lifting force F_l of the suction cup/cups [14]. This force is required to determine the area of the suction cup/cups distance from the flat surface and is calculated using the following formula:

$$F_l = p\frac{s}{t} \tag{2}$$

where

p – Vacuum level;

s – Effective suction area;

t – Safety factor - In the case of utilizing a horizontal placed cup $t \geq 4$; In the case of utilizing a vertical placed cup $t \geq 8$.

The label weight is very small (very often less than 1 g) so, from the point of the vacuum generation it is enough to use ejectors to achieve the requisite lifting force F_l. One of the representative applications of the IML gripper/tool is when one ejector is connected to more than one suction cup. The number of suction cups depends on the size of the label area and gripper/tool design. An adequate number of suction cups (SC) has to ensure that the label is not bending during the pick-up and transportation processes. Usually, the total number of suction cups and the ejector's capacity is greater than the values calculated by the formula (2). The typical pneumatic circuit of the vacuum system on the IML gripper/tool supplied by the ejector and several suction cups is shown in Fig. 2.

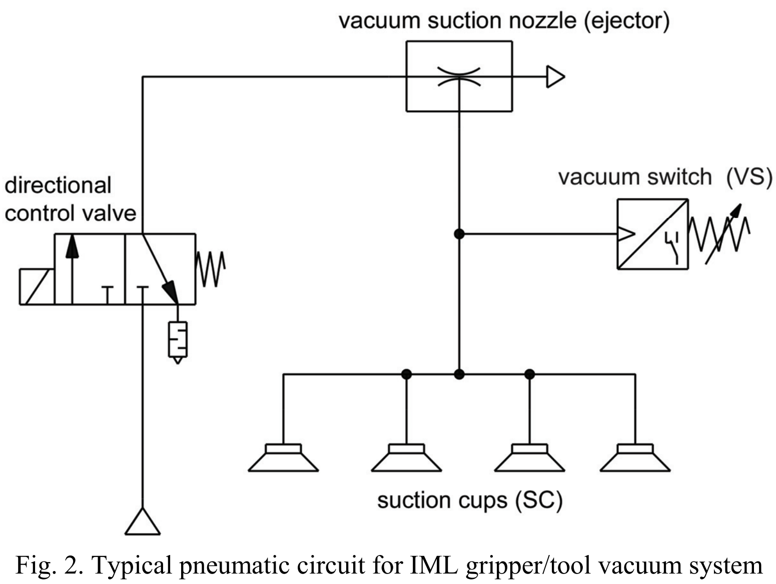


Fig. 2. Typical pneumatic circuit for IML gripper/tool vacuum system

As shown in Fig. 2, the gripper/tool is equipped with a vacuum switch (VS), used to detect the desired vacuum measured during the label pick up. Furthermore, this sensor is used to detect if the gripper/tool is holding the label during the transportation.

The key point in the post-mold process on IML robots is to obtain the accurate gripper/tool position during the label pick-up. Since the label thickness is very small (ranging from 50 to 500 microns [15]) it is not suitable for use with any of the position sensors, including encoders or potentiometers. Instead, several alternative approaches may be applied to determine optimal measurement devices, which are based on indirect detection of the label position in the container of IML robots. A conventional approach to designing the gripper/tool and the sequence of grasping the label is shown in Fig 3.

In the process of label grasping the first step is to move the gripper/tool closer to the labels (C in Fig. 3) in the storage. In this step, the cylinder extraction and vacuum system (B in Fig. 3) activation are done simultaneously (Fig 3a). In the next step the cylinder is extracted to its end position and the vacuum system grasps the label (Fig. 3b). This means that the mechanical device (A in Fig. 3) and proximity sensor (C in Fig. 3) can be used for label position detection. Further, the cylinder is retracted to its start position, while the vacuum system is still activated (Fig. 3c.). This is the final step in the sequence of grasping. The following sequence is to put the label in the mold of the IMM machine. At the end of this sequence, the vacuum system is turned off. These sequences are the same regardless of whether the mechanical device is used, or the pressure in the chambers of the pneumatic actuator is measured.

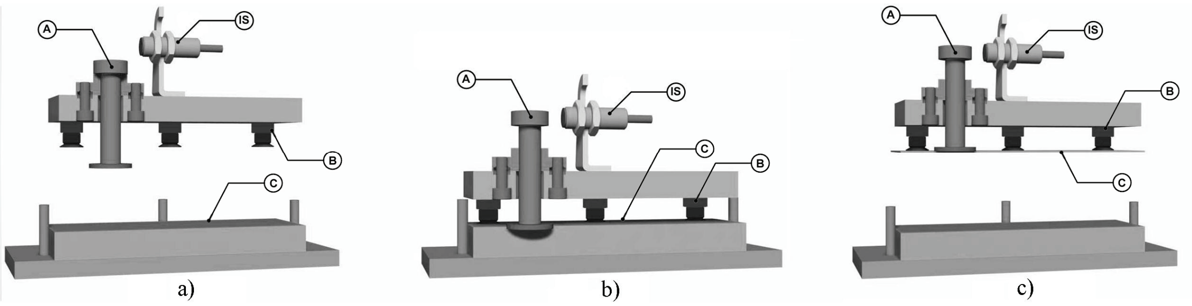


Fig. 3. Label grasping sequence with the mechanical device used for label position detection
a) Cylinder extraction b) Label grasping c) Cylinder retraction

Mechanical device and proximity sensor can be used for label position detection (in the storage). The detection principle of the mechanical device is based on moving a piston (A in Fig. 3). In most of the cases, the proximity sensors are of inductive type (IS in Fig. 3). In addition to some advantages such as simplicity, this approach has several disadvantages, including:

- The construction of the gripper/tool is complex;
- The gripper/tool is heavier, because it has more elements (piston support, piston, sensor, etc.);
- Assembly and maintenance are complicated;
- Failures in label grasping; according to research conducted in the Centre for Automation and Mechatronics - CAM (www.cam.co.rs) the percentage of failures in the worst cases is up to 1%, especially when changing label types or inadequately prepared label sets. Figure 4 shows the typical example of an error when the label has not been properly grasped. Such defective packaging must not be delivered to end users. There is an additional problem with detecting such defects, in particular where the injection molded packaging is packed automatically instead of manually.

Fig. 4. Result of the failure in label grasping (images of the defective and normal package)

Solving the last of the listed disadvantages has priority because it occurs in the operation mode. There are two problems that may cause failures in label grasping. The first may occur because of the movement of the piston in its support. The second may occur when the inductive sensor is used for detecting the end position of the piston.

If these problems exist, the gripper/tool will hit the labels in the container, which will result in the following:

- the first label not being picked up;
- the first label being picked up with errors in its position;
- the second label (the same case as the next one) being rotated from its regular position, and not being picked up adequately. It is quite probable that in the next cycle, the next label will not be adequately picked up.

Pursuant to the result of the previously described faults, the robot can produce poor plastic products. If such faults are timely identified, these situations can be overcome by:

- adjusting the piston movement;
- adjusting the position of the inductive sensor;
- adjusting the pneumatic actuator speeds.

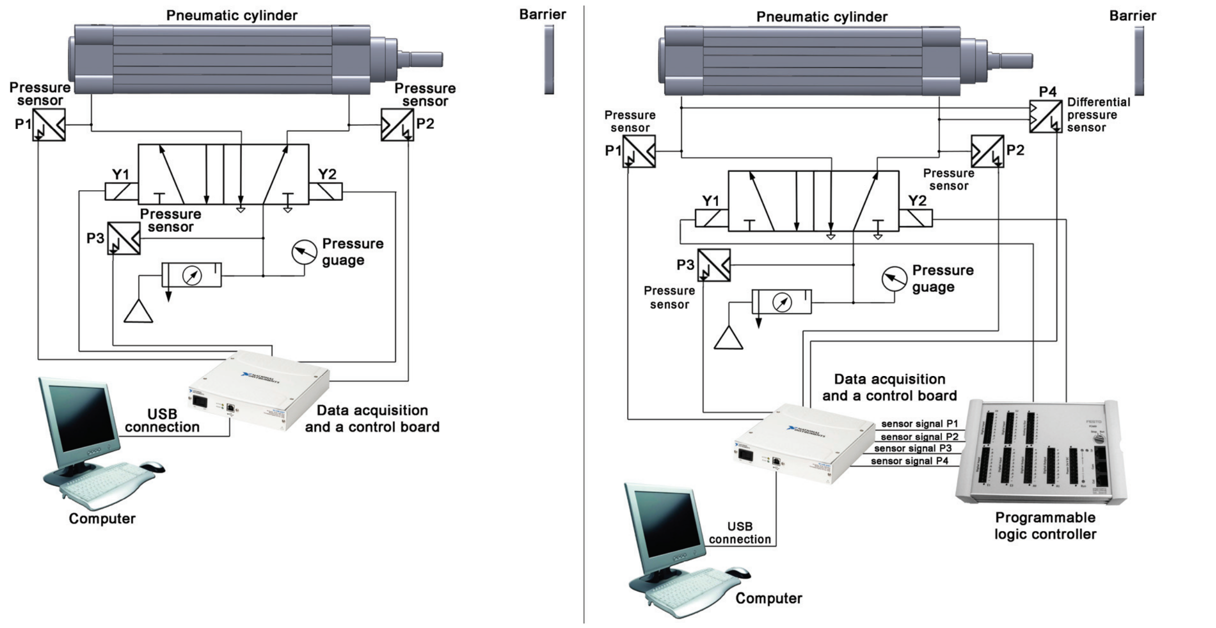
In order to avoid all the previously mentioned failure modes and undesired situations, a novel approach is proposed. This approach is based on measuring the pressure in the chambers of the pneumatic actuator as a way of detecting the position when the suction cups on the gripper/tool touch the label in the container on IML robots. At that moment, a signal is generated to enable retraction of the pneumatic actuator. This approach should enable a faster grasping label cycle, by increasing the speed of the pneumatic actuator and ensuring the reduced number of failures in labels grasping.

3. EXPERIMENTS

Most of the current researches on pneumatic position control systems in industrial applications have focused on using position sensors of actuators and different control strategies [16-18]. Researches on the use of pneumatic pressure were relatively rare, especially in the case of determining the position of a cylinder [19]. In order to determine and track the change of pressure in the chambers of the pneumatic actuator from its start point to the point when it touches the object, two experimental setups were developed. Their purpose is to define the control strategy which will be used in the control system of the manipulator for label grasping.

a) Experimental setups

The two experimental setups used in this research are shown in Fig. 5a and Fig. 5b. The first experimental setup (Fig. 5a) is used only to determine the change of pressure in the chambers of the pneumatic actuator. As a result, pressure curves will be defined, on which the changes of pressure in the chambers of the pneumatic actuator from its start point to the point when it touches an object are shown. The second (Fig. 5b) experimental setup is used to determine which of the applied control strategies, based on the pressure curves, suits the best. The gripper used in the experimental setups is shown in Fig. 6.



(a) (b)

Fig. 5. a) Experimental setup with the control board and the PC
b) Experimental setup with the control board, PC and the PLC

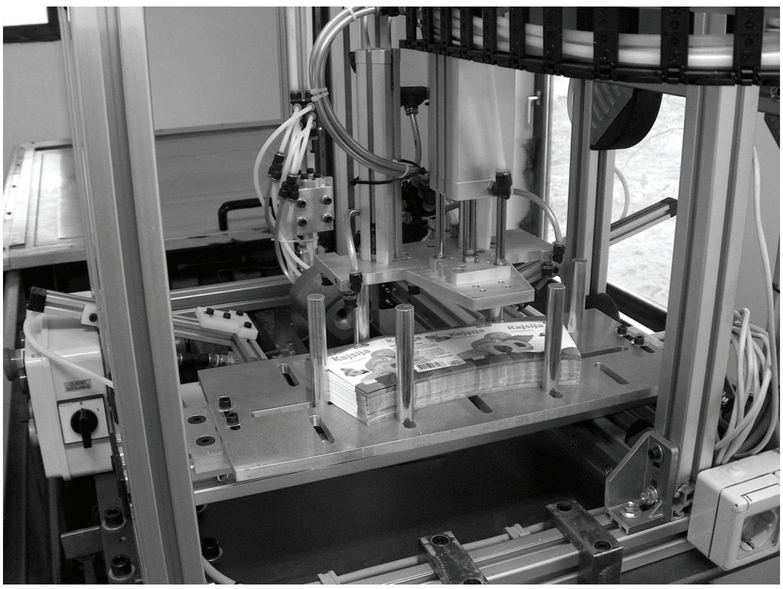


Fig. 6. Gripper used in the experiments

The double-acting cylinder is used as a pneumatic actuator. The diameter and the stroke of the pneumatic cylinder are 32 and 100 mm, respectively (FESTO code DNC-32-100-PPV). At the end of the pneumatic cylinder a metal board with a rubber cover is mounted. The weight of this load is 0.8 kg, which corresponds to the weight of the vacuum gripper/tool on the IML robot. Since the gripper/tool, in the case of IML robot, uses the vacuum system to grasp and hold the label, the area of the suction cup/cups distance from the flat surface corresponds to *s*, as calculated by the formula (2). The air supply pressure is 600 kPa, while the alignment angle is 270°.

Three pressure sensors, Danfoss MBS 3000 with an accuracy of ± 0.5% and pressure range 0-1000 kPa, were used for measuring the pressure in the piston, piston rod chambers of the pneumatic cylinder and in the air supply tube. The sensor outputs can be passed either to a PC through the data acquisition and control board (National Instrument, USB-6281, 18 bit, 625 kS/s) and/or a PLC (FESTO code is FEC 660) depending on the particular experiment.

b) Results

One of the experimental results is obtained with the first experimental setup (Fig. 7): the pressure curve, which shows the change of pressure in the piston chamber of the cylinder from its starting point until the point when the piston rod touches an object, i.e. reaches the end position (the point A in Fig. 7). The curve shown in Fig. 7 demonstrates the characteristic (typical) shape obtained after 300 completed cycles, with the charge pressure being set to 600 kPa. It should be noted that the presented curve shape was the same with 500 and 700 kPa charge pressures. The cylinder is controlled by bistable 5/2 directional control valve with the switching time of 13 ms (FESTO code CPE14-M1BH-5J-1/8).

Figure 7 clearly indicates that there are three zones of pressure changes. The first zone, at the beginning, before the start of the piston rod movement, the second one indicates the extension of the piston rod and the third displays the pressure change after the piston rod touches the object. In the first and the third zone, the value of pressure increases. However, in the second zone, after the pressure in the piston chamber reaches the first maximum, the pressure slightly decreases to the touching point.

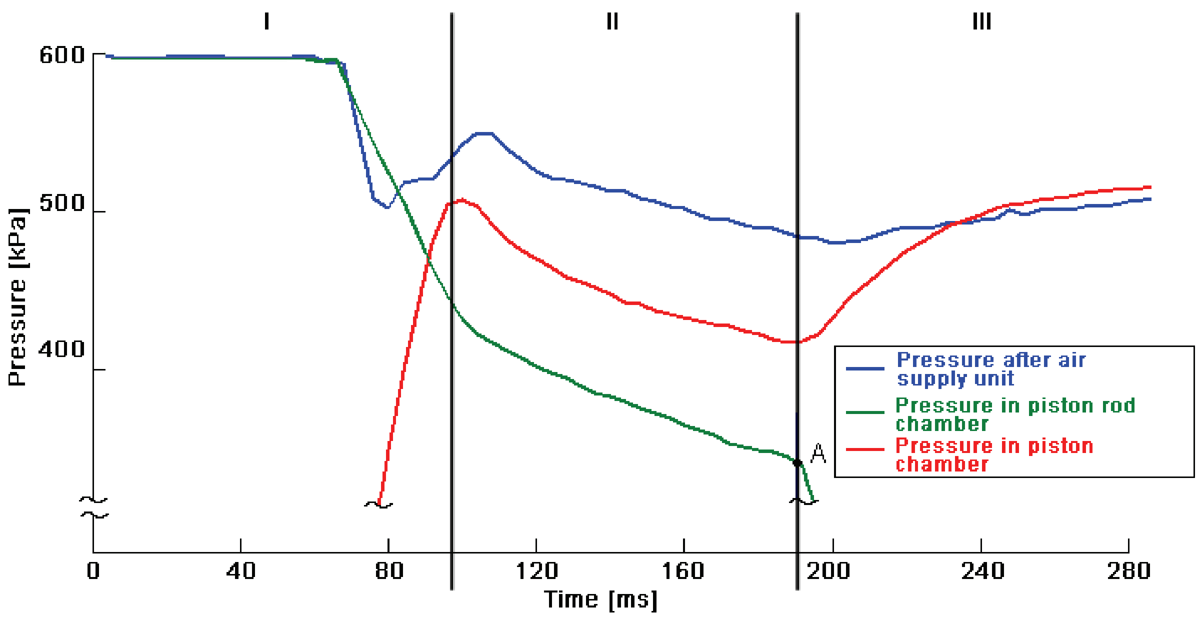


Fig. 7. Pressure change in the piston chamber of the cylinder

The conclusion that can be drawn from the results shown in Fig. 7 is that the key point for the controlling strategy is to identify the beginning of the third zone of the pressure change. Faster detection of the third zone enables a faster cycle of label grasping and decreases the number of failures. There are two measurement methods that may be used to change the pressure detection: using either the relative or the differential pressure as the measured variables.

In order to define which measurement method will provide a better response, three experiments were performed with the second experimental setup. More than 100,000 cycles were completed in each experiment, where the post-molding cycle time was up to 2 seconds. For all experiments over 300,000 cycles, the level of supply pressure in the piston chambers was set to 600 kPa. Figure 8 shows the PLC response time for each of those three experiments.

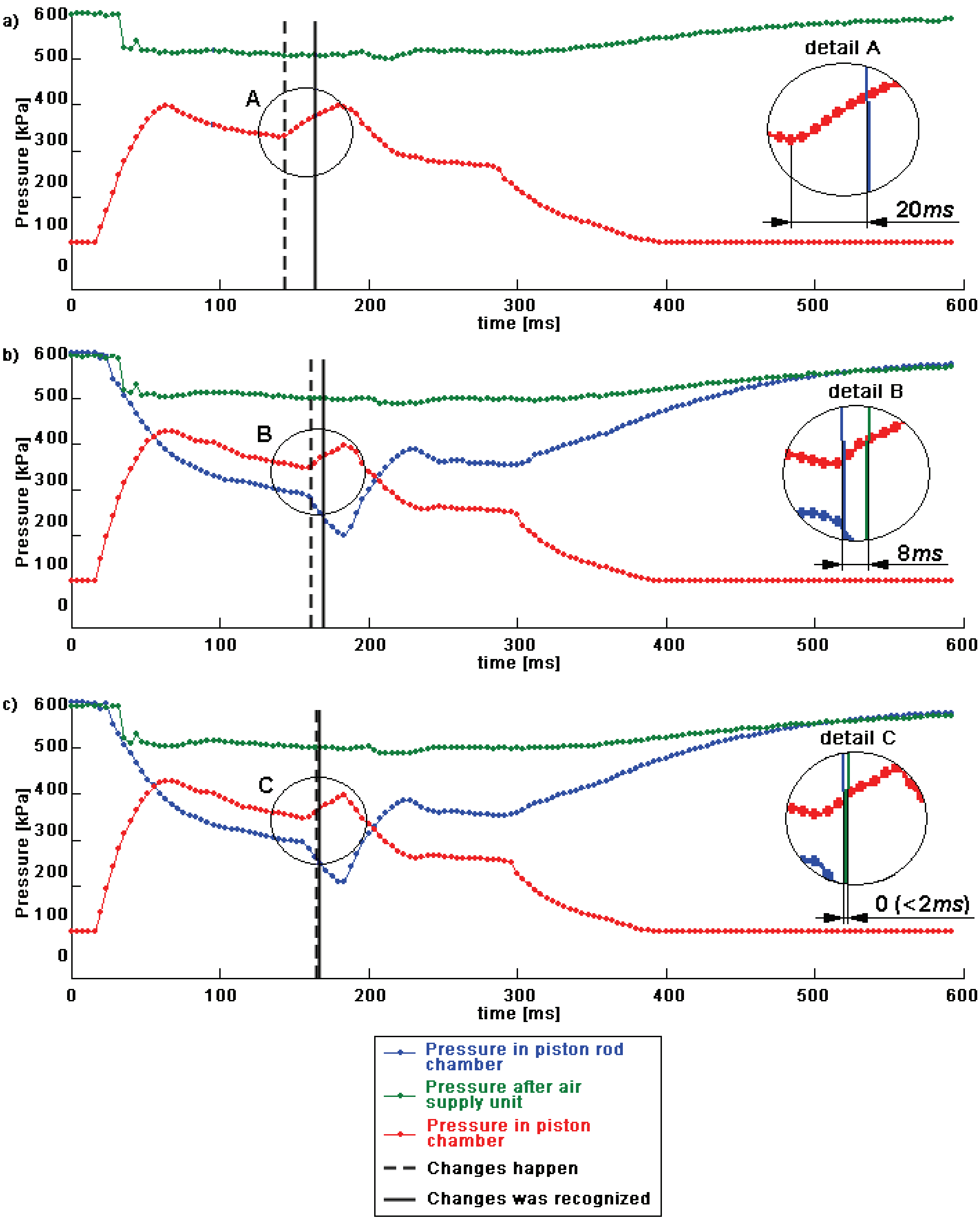


Fig. 8. PLC response time when measuring the pressure in the piston chamber of the cylinder
a) Using the analogue input for the measurement of pressure values. b) Using the digital input for detecting the output signal from the differential pressure sensor (with the preset value of difference pressures). c) Using the fast digital input for detecting the output signal from the differential pressure sensor (with the preset value of difference pressures).

In the first experiment, a separate PLC program was written for detecting the beginning of the third zone. The program was tracking the change in the pressure on the analogue input in order to identify the moment when the pressure shifts from the decreasing to increasing values. At that point, a special flag is set to 1. This moment is illustrated in Fig. 8a by the blue line.

In the second experiment, the differential pressure sensor with the preset value of pressure difference between the piston chamber and the piston rod chamber of the cylinder was used. Here, at the moment when the preset value is stepped up, the output signal from the sensor is generated. This signal is transmitted to the digital input on the PLC and monitored by the main control program. The blue line in Fig. 8b indicates the moment when the signal from the sensor is recorded.

In the third experiment, the same differential pressure sensor used in the second experiment is used here, but the output signal from the sensor was transmitted to the fast digital input on the PLC. At the moment, when the preset value was stepped up, the output signal from the sensor activated an interrupt function on the PLC. This moment is illustrated by the blue line in Fig. 8c.

The experiments described above are frequently used to conduct the grasping process control. Each of the described approaches has its own advantages and disadvantages, which will be discussed next.

4. DISCUSSION AND PRACTICAL IMPLEMENTATION

The first experiment which uses the analogue input on the PLC to measure the pressure yields rough results. The main reason is the slow PLC input transmission time. The range of the input transmission time is 8 to 14 ms (without the active communication interface – full active communication interface). In addition, the separate program in the PLC developed to detect the beginning of the third zone is time consuming. This is the most complex solution.

The simplest solution is to use digital input to detect the output signal from the differential pressure sensor. It has been used in the second experiment and its simplicity is reflected in the main control program, which contains the next condition statement:

```
IF diff_sensor THEN SET retract_solenoid
                    RESET extend_solenoid
```

Before this condition statement, it is necessary to put a delay. The delay has to overcome the signal from the differential sensor which is generated in the first zone. In other words, it is necessary to recognize a second leading edge from the differential sensor within one cycle of the cylinder. (Using a time delay function with a preset value of delay can be a problem in a situation when the movement of the cylinder is slowed down.)

The solution with the fastest digital input gives the best result. Fundamental to this solution is to use fast counter functions and the interrupt function. The fast counter is set to value 2 (two leading edges). When this preset value is reached, the interrupt function is activated. The interrupt function has the following statement:

```
IF NOP
THEN SET retract_solenoid
     RESET extend_solenoid
     RESET fast_counter
     SET flag_grasp
```

In the main program, the *flag grasp* has to be reset as soon as the signal for cylinder extension appears. The only weakness to this solution (as well as the previous one) is the adjustment of differential sensor value. The experimental results show that in most cases, the differences in pressures range from 60 to 80 kPa. However, in the same case, the fluctuation of the pressure in the main air supply can produce a false signal before the label is being touched. To prevent this false signal it is recommended to increase the preset value by a minimum of 100 kPa for differences of pressures. In the case of IML robot (www.cam.co.rs) the value of the differential sensor is set to 120 kPa.

Table 1 shows the errors identified after completing 100,000 cycles in all three experiments. It is evident that the number of errors in all the experiments is below 0.3 ‰**.** This result is by far more favourable than in the case of the mechanical system described in section 2, where the number of errors equalled 1%.

Table 1. The number of defective packages in the second experimental setup

Solution	No. of defective packages in 100,000 cycles
Using analogue input for pressure measurements	28
Using digital input for detection of output signal from the differential pressure sensor (with the preset value of differential pressures)	16
Using fast digital input for detection of output signal from the differential pressure sensor (with the preset value of differential pressures)	9

The data from Table 1 suggest that the use of the differential pressure sensor, the fast digital input, and the interrupt function would be the right choice for the improvement of the grasping processes on IML robots.

Another benefit of this solution is that it can be used not only for label grasping, but also for placing the label on the mold core of the IMM. This is another advantage of the suggested solution, in comparison to the mechanical system described in section 2. Moreover, the same principle can be used to extract the finished parts.

The mentioned solution has yet another possible application. If for any reason, the differential sensor fails, it is possible to use an ordinary pressure switch without changing the program. This possibility is not recommended, but can be used as a provisory solution.

5. CONCLUSION

The injection molding machines have many components and are available in different configurations. However, regardless of their design, injection-molding machines use the power source, injection unit, mold assembly, and clamping unit to perform all the stages of the process cycle. One of the basic parts of the fully automated IMMs is the IML robot, when it is necessary to introduce secondary operations such as subsequent printing and a spectrum of applications with special emphasis on food products packaging. IML robot is being used to position the labels into the mold cavity or mold core depending on the construction of the IMM.

The goal that has been established is to shorten the post-molding cycle. Having completed the analysis, the key point was determined, which was to find the best method for control of the pneumatic actuator. This paper presents a solution to this problem that is based on measuring the pressure in the chambers of the pneumatic actuator as a way to enhance the grasping process on the IML robots.

In the research, two experimental setups were established and experiments were carried out. The results indicate that the best solution to the problem is to use the fast digital input for detecting the output signal from the differential pressure sensor (with the preset value of differential pressures).

The problem of the vacuum system control for effective air consumption was not analyzed in this phase of research. This problem will be tackled in future research.

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