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Mould-integrated mechatronic fixture for error compensation in injection overmoulding of optoelectronic devices

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Abstract
Optoelectronic devices consist of electrical and optical components that are usually manufactured separately and assembled subsequently. To further enhance functional quality and at the same time shorten the production process, a new approach combines both steps by over-moulding the electric components with the lens material using injection moulding. During this process, aligning the electric components (e.g. LEDs) towards the lens geometry is a critical factor allowing for only very small tolerances. The accuracy of positioning the functional components on the printed circuit board (PCB) often does not fulfil the requested demands so that there is a need for compensating misalignment errors. For that purpose, a mould-integrated mechatronic fixture was developed, allowing for measurement-based alignment of optoelectronic components towards lens geometries within the injection-moulding tool. Principle concepts were derived incorporating functional requirements as well as boundary conditions for mould integration, resulting in a 3-DOF mechatronic fixture based on a compliant mechanism with piezo actuators. Model-based dimensioning and design of the prioritized principle as well as capabilities of the developed system will be discussed within the paper.

Opto-electronics, mechatronics, injection moulding, tooling

1. Introduction

The process of micro injection moulding is becoming increasingly important in the manufacturing of optoelectronic devices [1]. In particular, for the mass production of optoelectronic components, the joint production of the optics and the housing by overmoulding leadframes is of central importance (Figure 1). By saving additional assembly steps, a significant contribution can be made to increase the productivity in manufacturing of LEDs, lenses or optical sensors. Prerequisite for this are reproducible optical properties in the injection moulding process. In addition to the material properties of the plastics, particularly the geometric boundary conditions influence the optical behavior of the devices [2].

Especially in the case of integrating the components to one system, even slight shape and position tolerances of the injection moulding tool lead to a relative shift between optic and LED/leadframe. Figure 2 shows examples of lateral and angular misalignments.

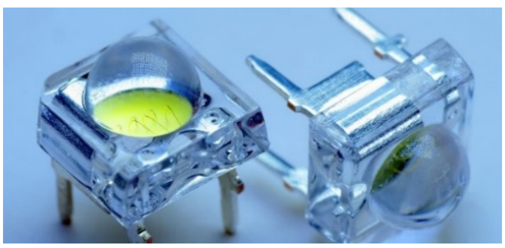

Figure 1 LEDs manufactured by injection overmoulding process [3]

The geometric tolerances of the leadframe and the core of the injection moulding tool cause insertion errors and thus misalignments between the cavity and the electrical component. These insertion errors represent a variable that is difficult to control and impede further automation, for example via robot handling [2].

The development of a mould-integrated mechatronic fixture aims for the detection of misalignments and error compensation within the mould. This will enable better controllability and automation of the overmoulding of optoeletronic components.

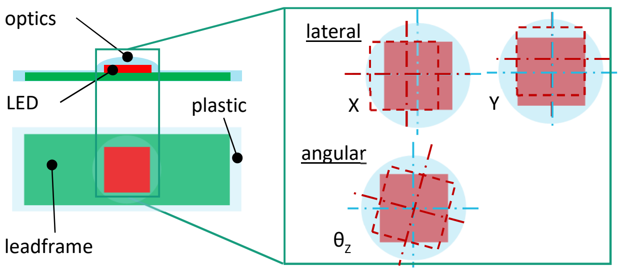

Figure 2 Misalignment errors in moulding tools

2. Development of concept

For the integration of the mechatronic fixture in a micro-injection mould a compact design is necessary. To compensate for the misalignments, high positioning accuracy and resolving power of the kinematics are required.

Table 1 shows the specifications of the mechatronic fixture.

Table 1 *Specifications of the mechatronic fixture*

available space	70 mm x 70 mm x 130 mm
workpiece dimensions	35 mm x 35 mm x 13 mm
translator travel x,y	± 300 µm
rotatory actuating angle Θ_Z	± 1.8°
translational positioning accuracy	0.1 µm
rotatory positioning accuracy	0.006°
operating temperature	80°C
closing force tool	10 kN
incjection pressure	50 bar

Conventional transmission links in the form of rigid body mechanisms with contact bearings are subject to friction as well as play and thus unable to meet the requirements of the movement accuracy. Therefore mechanisms with flexible joints are used in the axis, which are both free of friction, play and wear. This will allow for highly precise motion guidance in submicrometer range as well as compact dimensions [4].

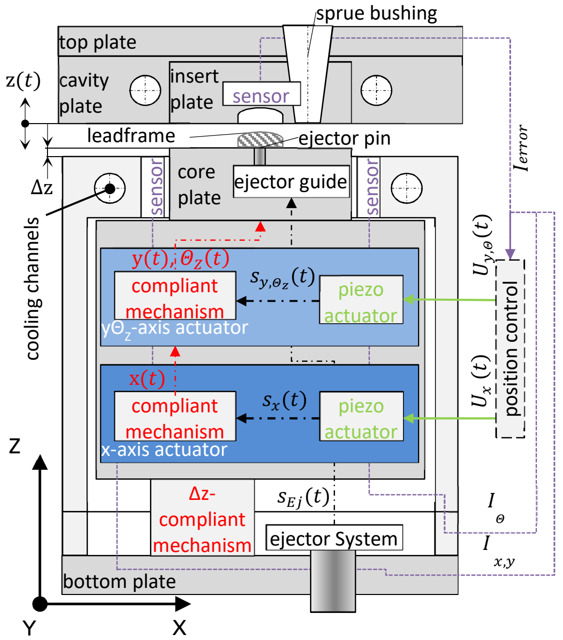

Figure 3 Functional diagram of mould-integrated mechatronic fixture

To meet the restrictions of the installation space of an injection moulding tool, a serial structure of the kinematics has been selected (Figure 3). The actuators first generate stroke $s_x(t)$ and $s_{y,\Theta_Z}(t)$, which are transmitted by the mechanisms. The x-axis actuator shifts the layer of the y-Θ_Z-axis actuator in $x(t)$ while it is connected to the core plate and finally allows for movement in $y(t)$ and rotation $\Theta_Z(t)$ around z. Since the leadframe is located in the core, a three-axis-alignment is possible. Whereby a sensor integrated in the cavity detects the misalignment of the component. This information is passed back to the control system. The sensors in the lower part of the mould detect the actual position of the core and enable position-controlled tracking of the axes.

3. Development of the 3-DOF flexure-based mechanism

Due to the increasing importance of compliant mechanisms in micropositioning and microhandling techniques, a variety of synthesis methods are known [4]. In addition to the use of gearboxes and the optimization of mechanical structures using methods for continuum structures, the substitution of rigid-body mechanisms is the most widely used synthetis variant. This method can also be used in the development of compliant mechanisms [5].

3.1 Kinematic structure

In a first step, different types of levers can be evaluated in terms of their installation space, range of motion and gear ratio. In particular, levers of the bridge type are most advantageous because they spatially integrate the actuator and enable precise movement guidance [6]. In a second step, the individual bridge type levers have to be arranged into combined rigid body mechanisms that fulfill the respective movement tasks of the axes. According to Figure 3, a rigid body mechanism must be developed allowing movement in x, y and Θ_Z (Figure 4).

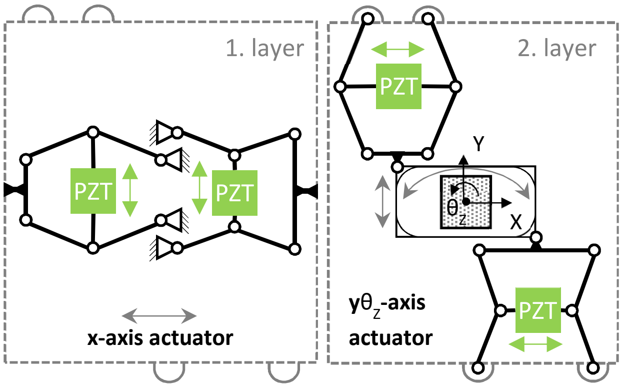

Figure 4 Kinematic structure of actuator axis with rigid body mechanisms

The symmetric arrangement of the mechanisms in the axes enables the actuator to be thermo-symmetrical, which is necessary for the performance at operating temperatures. In addition, possible manufacturing errors in the flexure joints can be adjusted later by the parallel arrangement of the actuators.

As can be seen in Figure 4, the actuators should not be operated in a differential arrangement, but should initiate the movement together in a serial arrangement. Only the rotation around Θ_Z should be achieved by an opposing actuator stroke in layer 2. In order to achieve the greatest possible stroke of the axes in the compact installation space, the piezo actuators should be preloaded by the mechanism itself.

3.1 Flexure design

The rigid body mechanism is replaced by the use of concentrated compliance at the joints. Therefore swivel joints of the rigid body mechanism with a degree of freedom 1 are now substituted. Simple bending joints were used. Since they are easy to manufacture they offer a good basis for parameter optimization and, depending on the width, they offer high stiffness against deformation of the mechanism due to the clamping force.

A parameterized simulation model (Figure 5) enables a parameter study to optimize the maximum displacement with low material tension. On the one hand, the geometric parameters of the bridge type levers serve themselves. The height offset in the joint u, the length of the bending beam l, the width of the mechanism w and the joint angle α. On the other hand, the stiffness behavior of the actuator has to be taken into account, because it provides a shorter stroke with increasing rigidity of the mechanism.

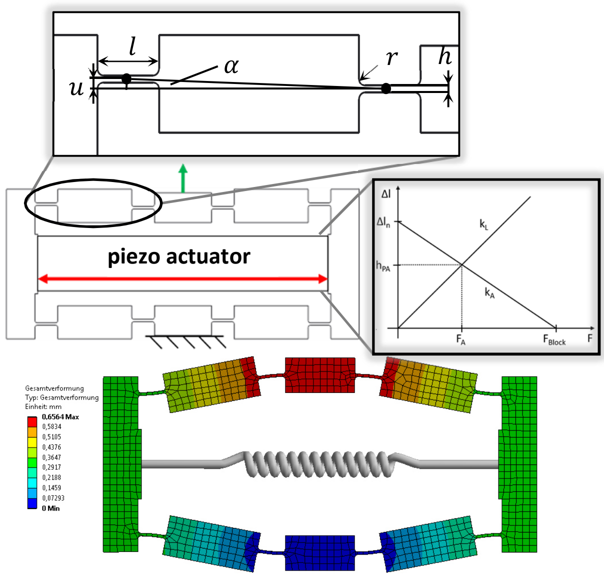

Figure 5 Parameterized simulation model of a bridge type lever

Parameter sets can be defined based on the geometric boundary conditions for installing the actuators and the installation space of the actuators. Design recommendations already exist for the radius r of the joints [7]. Therefore, an investigation was carried out for four parameters. The height offset u was defined as a function of α and l due to the geometric boundary conditions. Figure 6 shows the result set of an actuator-bridge combination.

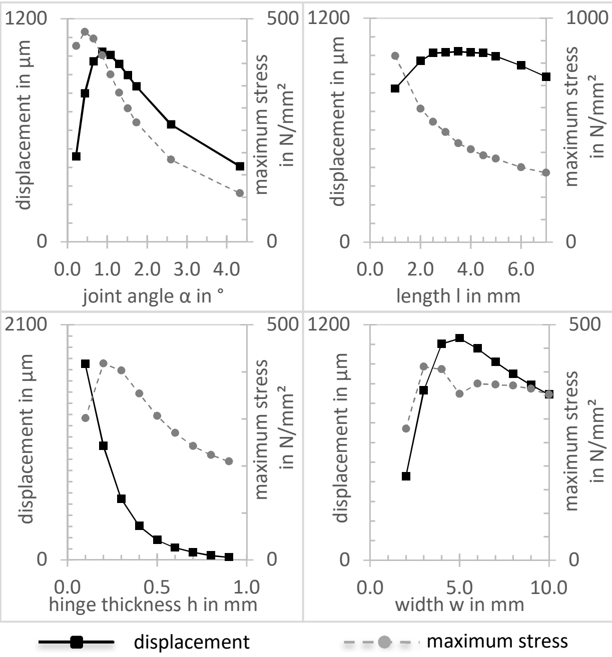

Figure 6 Example result set of the parameter study

Based on the results of the parameter studies for various actuator-bridge combinations, an optimized design is arranged according to the kinematic structure. The design of the complaint mechanism is fixed by defining the geometric parameters of the flexure joint (Figure 7).

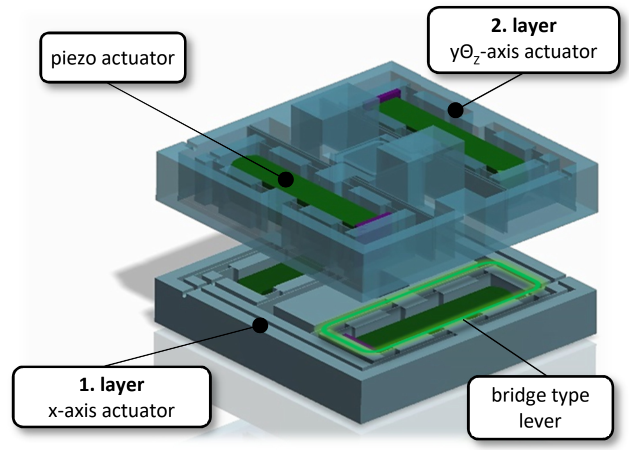

Figure 7 Design with stacked x- and y-Θz-axis

3.3 Mould integration concept

Additional design measures are necessary to integrate the mechanism into an injection mould. Since the mechanism is connected to the core of the injection moulding tool, it is up to the flux of the closing force. The impact on the actuators would lead to an exeedance of the maximum material tension. For this reason, an additional z-direction compensation mechanism has been integrated, which allows the 3-DOF mechanism to be guided in parallel. A flexible joint lifts the actuator system upwards with Δz when the tool is open. When the tool closes, the parallel mechanism guides the actuator and the core until the core contacts a stop surface in the lower part of the mould. This ensures that the clamping force is distributed over the mould and the actuator system is not damaged (Figure 8). Since the flux of force between the upper and lower part closes, no major deformation of the device is to be expected, since these components have a high degree of stiffness.

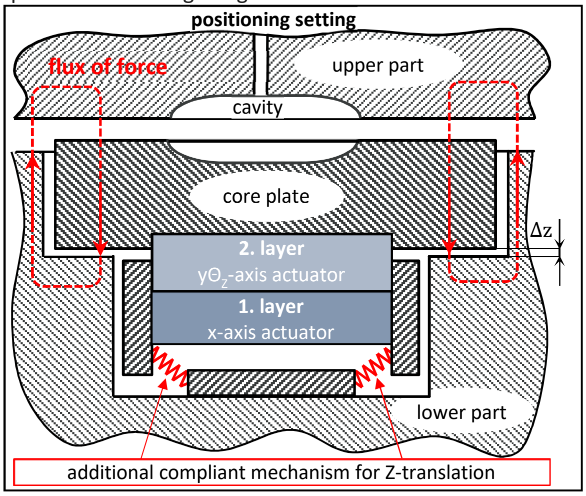

Figure 8 Principle of decoupling the closing force

For a productive injection moulding process, it is essential that the fully moulded optoelectronic components can be automatically removed from the mould. Therefore, the next design step was the implementation of an ejector system. For this, the already existing ejector system was divided. The lower part of the ejector pin remains connected to the usual ejector system, while the upper part is integrated into the core of the tool. For this purpose, an additional guide hole was inserted and the ejector pin was installed pretensioned by a compression spring. The lower part of the pin only makes contact during an ejection process and moves the pin in to the core to a demoulding movement.

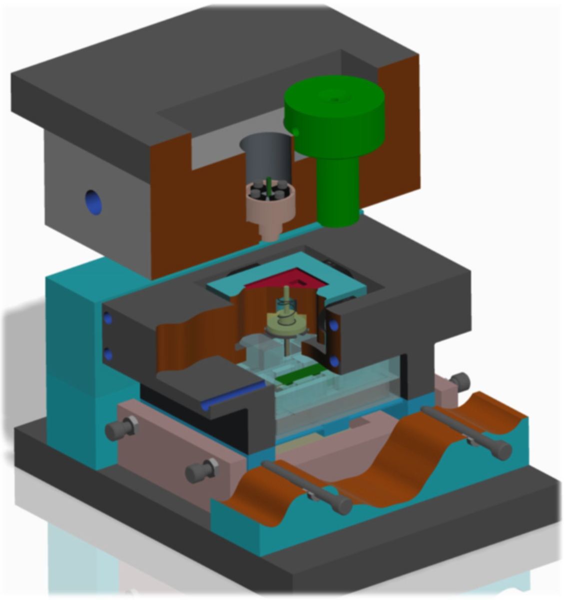
Figure 9 Design of a mould-integrated mechatronic fixture

The core is surrounded by three capacitive flat sensors in the injection mould. One sensor is directed to the x-axis and two sensors to the y-direction to detect the angular- and the y-position of the core. These sensors have compact dimensions and a measurement resolution in the nanometer range. A fiber-optic measuring system is integrated in to the insert plate in the center of the cavity, which enables the detection of the misalignments of the electrical component (Figure 9). The integration of an inline fiber optic measurement system in moulding tools has already been tested in [8].

4. Thermal behavior and motion analysis

A preload by the mechanism itself was applied when integrating the actuators. The pretension was selected so that the pretension of the actuators is always above the minimum pre-tension during the heating process. The different thermal expansion coefficients of the piezoceramic and the steel of the compliant mechanism were taken into account in a simulation of the heating process to the operating temperature of the mould to 80°C. A pure piezoelectric stack has a slightly negative expansion coefficient. The metallic contact plates and the adhesive layers, however, result in a non-linear, slightly positive expansion behavior of the piezo actuator [9]. Due to the significantly higher thermal expansion coefficient of steel, the mechanism drifts thermally. This also reduces the preload on the actuators. At the operating temperature the actuator has a larger adjustment range (x=351 µm/y=313 µm) than at 20°C (x=323 µm/y=278 µm) due to the load-dependent stroke behavior of the piezo stack actuator.

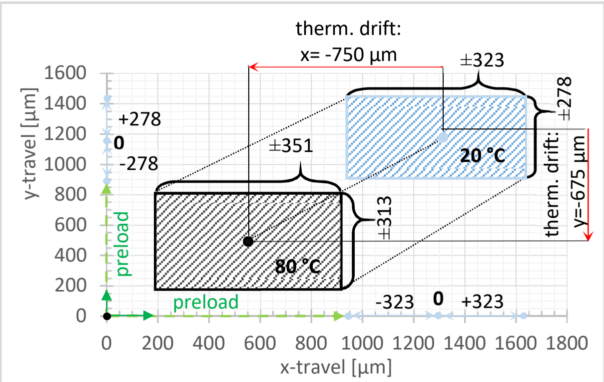

Figure 10 X/Y-travel for initial and operation temperature

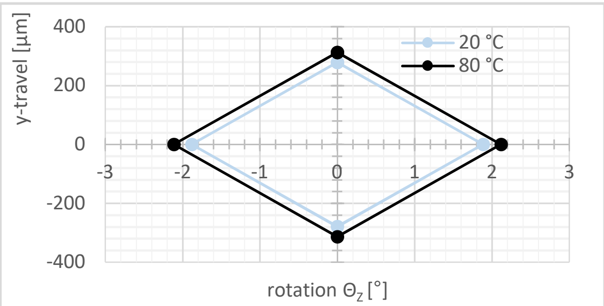

Figure 11 Y-travel and rotation Θ_Z for initial and operation temperature

Figures 10 and 11 show the temperature-dependent movement behavior of the mechanism. Not only the translational adjustments increase, but also the maximum angle Θ_Z from 1.9° to 2.1°. Due to the lower actuator preload, the actuator stroke increases from 27 to 29 µm in the x-axis and from 25 to 28 µm in the y-axis. Since a thermosymmetric structure was already taken into account when designing the kinematics, the gear ratio remains unaffected by these thermal drifts. This leads to the transfer functions of the axes of motion

$$x(t) = \frac{s_{x1}(t) + s_{x2}(t)}{2} \cdot 24.1$$
$$s_{x1}(t) = s_{x2}(t) \qquad (1)$$

$$y(t) = \frac{s_{y1}(t) + s_{y2}(t)}{2} \cdot 22.3 \qquad (2)$$

$$\Theta_Z(t) = (s_{y1}(t) - s_{y2}(t)) \cdot 0.077 \frac{\circ}{\mu m}. \qquad (3)$$

The advantage of the symmetrical structure of the x- and y-actuators is that no adjustment or calibration of the control parameters is necessary even after the mechanism has warmed up. However, the amount of thermal drift exceeds the range of motion of the axes. Therefore, once the operating temperature has been reached during initial system setup, the device can be finally aligned using an arrangement of adjusting screws.

5. Conclusion

The paper presents an innovative approach to align electronic components in injection moulding tools. This is to make the overmoulding of optoelectronic components more reliable and to replace additional measuring and assembly steps. Especially for the production of micro-optoelectronic components, the new actuator system offers the possibility to compensate geometrical tolerances of the mould and the printed circuit boards. For this purpose, the device provides three axes to align the components in the tool. Lateral errors of up to 300 µm and angular errors of 2° can be compensated. The kinematics were developed in conjunction with the use of piezo actuators. This enables highly precise and reproducible motion control. After assembly and commissioning of the mould-integrated mechatronic fixture, further investigations into the temperature behaviour, the influence of the closing and process forces and the measurement deviations of the sensor systems are carried out. In a demonstrator tool further technological investigations will be carried out in the injection moulding process for novel optoelectronic components.

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