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# The evolution and future trends of the mounting of high-performance optics

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**Abstract**

High-performance projection optics must meet very tough specifications since the early phase of the development of semiconductor manufacturing machines. One key issue has always been the mounting of optical elements. The last three decades witnessed continuous evolution in the technologies used in this context. Whereas the first successful ideas consisted in clamping the optical elements to the housing aiming at a rigid connection and small relative motions within the projection optics, later approaches rely on controlling the position and orientation of kinematically determined parallel manipulators holding the optical elements. For understanding this evolution and anticipating future trends, a review of different mounting technologies together with the increasing demands to high-performance optics is essential. To this end, this paper revisits some mounting technologies and recalls the basic kinematic principles needed to understand these technologies.
Three phases can be distinguished in the evolution of the mounting of optical elements. Correspondingly, this paper is divided into three sections. The first section outlines the very first mounting solutions that were used in projection optics. The second section emphasizes the reasons that lead to the use of manipulators. The last section addresses further challenges and proposes kinematically over-determined manipulators to meet the requirements expected in future developments.

Keywords: Semiconductor Manufacturing, Mounting Technologies, Optomechanics, Optics, Kinematics

## 1. Introduction

The mounting technologies of high-performance optics evolved in three phases. In the first phase, passive mounting technologies were dominant. Later, kinematically determined monipulators become the state-of-the-art. In the near future, it is expected that kinematically over-determined manipulators are needed to cope with the increasing demands. But first, it is important to recall the fundamental problem of mounting optical elements. It is generally required that optical elements, often made of glass, are mounted inside a housing, often made of metal, that isolates the optical elements from different environmental disturbances, like shocks, vibrations, thermal disturbances etc. One crucial task consists therefore in solving the problem of fixing the optical elements to the housing. The first section revisits the passive mounting of optical elements. The second section emphasizes the need of using manipulators to enable high-accurate alignment of the optical element. The third section proposes kinematically over-determined manipulators to meet the requirements expected in future developments.

## 2. Passive mounting of optical elements

The first phase of the mounting of high-performance optics relies on axial and radial clamping [1]. As the requirements become tougher, decoupling the optical elements from the housing gains in importance. Elastic hinges are then necessary and must be designed to decouple the optical element from its environment.

### *2.1. Clamping and adhesives*

The most intuitive way of mounting an optical element to the housing is clamping it. Hard clamping, as depicted in **Figure 1(a)**, is clearly simple and cost-effective. If the available volume for the mounting is limited, adhesives, as depicted in **Figure 1(b)**, are often used to fix the optical element to the housing [2]. Morevover, both clamping and glueing allow for a radial mouting of the optical element. It induces however more mechanical stress and surface distortions. The result is often poor optical performance, especially when the system is subject to thermal and mechanical disturbances.

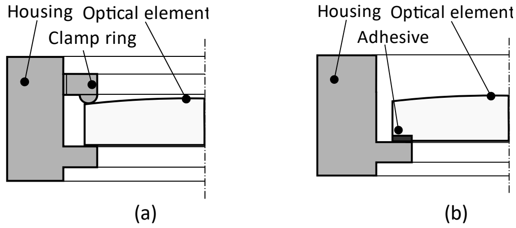
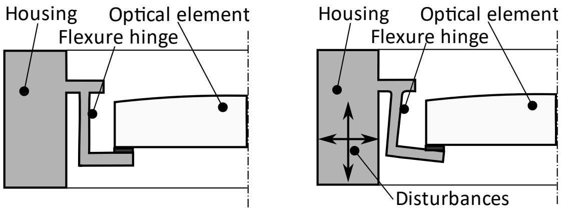



**Figure 1.** First mounting solutions rely on clamping and adhesives

The increasing demands and the sensitivity of larger optical elements to disturbances compel engineers to design a better decouping of the optical element. One decisive idea is the use of elastic hinges.

### *2.2. Use of elastic hinges*

**Figure 2** depicts an optical element mounted on flexure hinges. Each elastic hinge has 2 degrees of freedom allowing therefore each mounting point of the optical element to move in a horizontal and vertical direction. In this way, thermal and mechanical disturbances coming from the housing are attenuated and don't induce mechanical stresses in the optical element.




(a) (b)

**Figure 2.** Elastic hinges for decoupling optical elements

The main drawback of passive mounting is the fact that an alignment of the optical element is challenging and time-consuming, since it is achieved by means of machine tolerances of the components and shims [2]. A more adequate way of aligning the optical element is to use a manipulator. The next section addresses this issue.

## 3. Kinematically determined manipulators

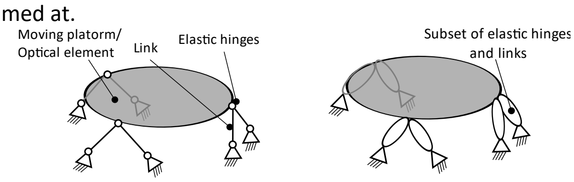
A manipulator consists of several links connected with hinges. In this context, the fixed frame corresponds to the housing, and the moving platform corresponds to the optical element. Such a system must first ensure that the desired number of degrees of freedom (DoF) needed for alignment is met. To this end, the mobility of the manipulator is investigated in the first subsection. The second subsection addresses parasitic forces and moments that arise from the manipulation of the optical element.

### *3.1. The mobility of a manipulator*

Figure 3(a) depicts an optical element that is connected by means of six links to a fixed frame. Clearly, the optical element is the moving platform of this manipulator. One crucial issue in designing such a manipulator is to find out the degrees of freedom needed in each link so that the whole mechanism is kinematically determined. The Grübler formula [3] can be used for this purpose. For simplicity of exposition, each limb is replaced by a subset of links and elastic hinges as shown in Figure 3(b). The final system has one fixed frame, one moving platform and six joints. By means of the Grübler formula, it is now possible to find out the number of degrees of freedom for each subset

$$F = 6(n - 1 - j) + \sum_j f_j$$

The final mechanism is kinematically determined, if the mobility number $F$ equals zero. Referring to Figure 3(b), the number of parts building up the manipulator is $n = 2$ , i.e. the fixed frame and the moving platform, the number of subsets is $j = 6$. Hence, the sum of all degrees of freedom needed in the six subsets is $\sum_j f_j = F - 6(n - 1 - j) = 30$ for having $F = 0$. In other words, the number of degrees of freedom in each subset should be five, if a kinematically determined manipulator is aimed at.



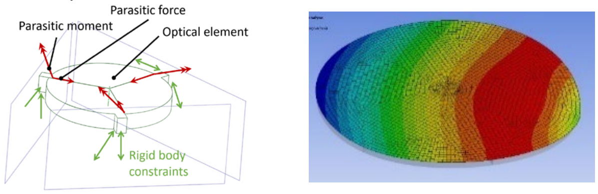

(a) (b)

**Figure 3.** Kinematically determined manipulator

An alignment of the optical element can be carried out by actuating the limbs depicted in Figure 3(a). Six actuators will add six degrees of freedom to the platform so that the optical element can be positioned and oriented in the 6-dimenstional space in order to achieve the desired alignment. After the alignment, the actuators are locked, the mobility number is zero again $F = 0$.

### *3.2. Parasitic forces and moments*

As seen in Section 2.2, elastic hinges are often used. Although the manipulator is kinematically exactly constrained, the hinges, when deformed, react with internal forces and moments that are transmitted to the optical element according to Figure 4(a). These forces and moments are called parasitic and lead to distortions of the optical surface. This, in turn, causes optical aberrations. Figure 5 shows the impact of a tangential moment on the optical element.




(a) (b)

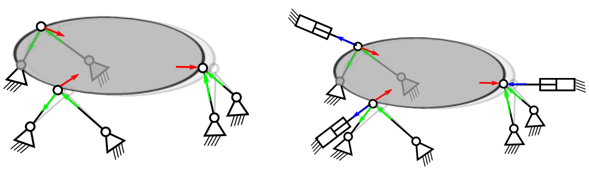
**Figure 4.** (note: larger figures can be set over 2 text columns)

Consequently, even if a kinematically determined manipulator is properly designed, distortions of the optical surface cannot be prevented, especially when alignment is needed and elastic hinges are used. As the demands to the optical surface increase, parasitic forces and moments become a challenge. So, reducing them is a key issue in further devolpments of high-precision manipulators. Kinematically over-determined manipulators are therefore more in the focus.

## 4. Kinematically over-determined manipulators

As seen in the previous section, it is not sufficient to ensure that the manipulator is kinematically determined for minimizing the distortions of the optical surface. A reduction of parasitic forces and moments is necessary in order to obtain better optical performance.

If the optical element is moved for alignment purposes, parasitic forces and moments arise according to Figure 5(a) and deform the optical surface. As far as radial forces are concerned, additional radial actuators can be added to the manipulator according to Figure 5(b). These exert forces that counteract forces going through the optical element. Hence, parasitic radial forces and thereby the distortions of the optical surface can be minimized. Although six DoFs are needed for the alignment process, more than six actuators are used. This redundancy is used to minimize the forces on the optical element and to improve the optical performance.



(a) (b)

**Figure 5.** Motivation for using over-determined manipulators

## 5. Conclusion

This paper addresses the evolution of the technologies used in the mounting of optical elements. Kinematically over-determined manipulators are expected to gain in importance, as the demands for accurate manipulators increase.

## References

[1] Yoder, Paul R. *Opto-Mechanical Systems Design*. Marcel Dekker, Inc. 1986.
[2] Leach, R., & Smith, S.T. (Eds.). Basics of Precision Engineering (1st ed.). CRC Press. 2018.
[3] Grübler, Martin. *Getriebelehre. Eine Theorie des Zwangslaufs und der ebenen Mechanismen*. Berlin: Verlag Julius Springer. 1917.