Mechanisms and Machine Science

Erwin-Christian Lovasz
Gondi Kondaiah Ananthasuresh
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Victor Petuya *Editors*

Microactuators and Micromechanisms

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Preface

The third Conference on Microactuators and Micromechanisms, MAMM-2014, was organized by the Department of Mechatronics at the Faculty of Mechanical Engineering, Politehnica University of Timisoara, under the patronage of the International Federation for the Promotion of Mechanism and Machine Science (IFToMM) Technical Committees for Linkages and Mechanical Controls and for Micromachines.

The Conference aims to bring together researchers and students who develop their work in disciplines associated with micromechanisms and microactuators in a friendly, colleague-like, and collaborative environment. MAMM-2014 offers a great opportunity for scientists all over the world to present their achievements, exchange innovative ideas, and create solid international links. The scientific event was meant to gather the novelty and originality in machine science and to depict the trend of this important and creative field.

The topics proposed for the Conference are Microactuators and micro-assembly, Micro sensors involving movable solids, Micro-opto-mechanical device, Mechanical tools for cell and tissue studies, Micromanipulation and micro-stages, Microscale flight and swimming, Micro-robotics and surgical tools, Micron-scale power generation, Miniature manufacturing machines, Micromechatronics and micromechanisms, Biomechanics micro and nano scales and Control issues in microsystems.

We would like to express our grateful thanks to IFToMM, to the Romania IFToMM National Committee (ARoTMM), and to the members of the International Scientific Committee of MAMM-2014.

We appreciate the effort of the reviewers gathered in the International Scientific Committee of MAMM-2014. They spent time on a serious work of evaluation and improvement guidance, meant to assure high quality in all papers.

We thank the authors, who contributed with valuable papers on different subjects covering the wide scientific fiels of Mechanisms and Machine Science.

We thank the Department of Mechatronics at the Faculty of Mechanical Engineering, Politehnica University of Timisoara, for hosting the scientific event and

supporting all associated activities. The third Conference on Microactuators and Micromechanisms became a reality due to a hardworking local organizing team: Gruescu Corina Mihaela, Inocenţiu Maniu, Valentin Ciupe, Iosif Cărăbaş, Nicolae Mircea Dehelean, Valer Dolga, Florina Pop, Cristian Pop, Dan Teodor Mărgineanu, Cristian Emil Moldovan, and Eugen Sever Zăbavă.

Last but not least, we are grateful to the staff at Springer Publishing for their excellent technical and editorial support.

Timisoara, Romania
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Erwin-Christian Lovasz
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A Compliant Mechanism as Rocker Arm with Spring Capability for Precision Engineering Applications

L. Hartmann and L. Zentner

Abstract In precision engineering escapement and ratchet mechanism are often used to keep an element in a non-operating state e.g. in chronometers. Such mechanisms have a pivoted and spring-loaded pawl locking a ratchet. For miniaturized applications reducing the number of elements and functional integration is recommended. Spring clip mechanisms as rocker arms combine the rocker itself with a spring. Therefor a special formed wire is mounted in a frame by two shifted revolute joints. The spring capability is once determined by the geometry and the material and twice by the shifting of the axes and the deflection of the clip. In this contribution the force-deflection behavior of such mechanisms for different shiftings is focused utilizing the finite element method. Spring clip mechanisms realize a wide range of motion and due to a shifting of axes and the asymmetry the force-deflection behavior is influenced. Finally some precision engineering devices with a spring clip mechanism are suggested.

Keywords Compliant mechanism • Precision engineering • Rocker arm • Spring • Spring clip mechanism

1 Introduction

Designing scientific and measuring instruments or highly accurate devices, such as chronometers, medical and optical apparatus, is a part of precision engineering. Usually the motion of parts and assemblies in precision engineering is characterized by high velocities but the inertia has to be exceptionally low (Bischoff 1959; Hildebrand 1967; Schilling 1989). To reach a high precision and a minor inertia, the components and machine elements of such devices have small dimensions and consequently a low mass. So, downsizing of these elements is recommended and this is a reason for integration of functions. Additionally, manufacturing and assembling of miniaturized and function integrated components is more difficult than macro machine elements.

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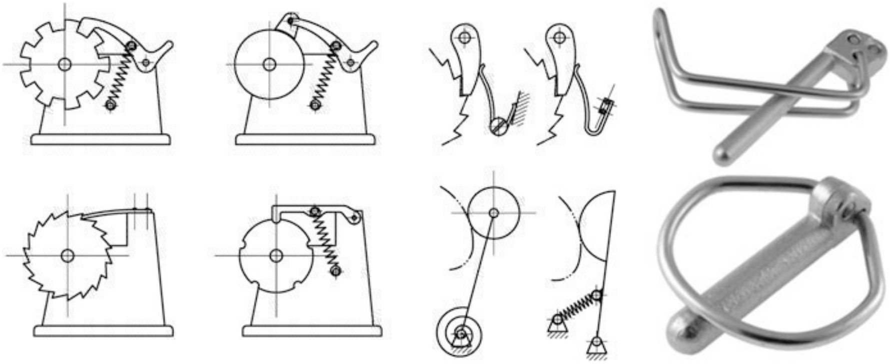


Fig. 1 Escapement and ratchet mechanisms with spring-loaded pawls, cam mechanism with different spring loaded rocker arms, linchpins as examples for spring clip mechanisms (Bischoff 1959; Hildebrand 1967; RÜBIG GmbH & Co. 2013; Schilling 1989)

In several precision engineering devices escapement and ratchet mechanisms are used to keep an element in a non-operating state, Fig. 1. Therefor a ratchet is locked by a pawl, which is usually pivoted and spring-loaded. Also in cam mechanisms springs are used to keep the mechanism elements in contact, Fig. 1. The spring in each application can be a coil spring or a bending spring. For a bending spring like a cantilever beam the range of motion is strictly limited because of the mechanical stress. To realize a wide range of motion a rocker arm is loaded by tension or spiral springs but these are additional parts in construction. With a look at mechanisms with pivotally mounted rockers, especially escapement and ratchet mechanism, we introduce a spring clip mechanism as a rocker arm with spring capability for precision engineering applications. Spring clip mechanisms as compliant mechanisms consist of a specially shaped spring clip (wire bracket) with bending and torsional capability which is mounted in a rigid frame by two revolute joints with shifted axes, Fig. 1. The spring capability is determined by the geometry, the material, the distance between the two shifted axes (displacement) and the deflection of the clip. We aim to investigate the force-deflection behavior of such a mechanism for different displacements.

2 Material and Methods

Analyzing spring clip mechanisms and to investigate their stiffness behavior mechanisms we suggest a model to use the finite element method.

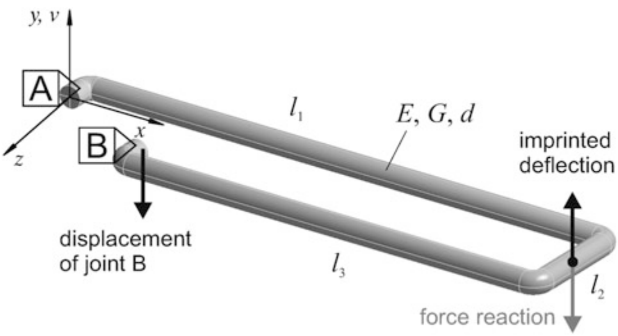
2.1 Modeling

An essential part in the investigation of a spring clip mechanism is the modeling. Generally, there are several specially formed spring clips, each adapted for one special application. Because it is impossible to focus on all of them, one particular spring clip is chosen for the investigation. The spring clip mechanism we use for studying has features and restrictions as follows (Hartmann and Zentner 2013):

- it is built up of three bending and torsion flexible, straight legs,
- in undeformed state it is planar, meaning that all bar axes are within one plane and all legs are perpendicular to each other,
- asymmetry occurs because of the different lengths of the two parallel legs,
- slender legs with small and constant circular cross-sections throughout the length of all legs ,
- plane sections remain plane and normal to the deflected neutral axis,
- the material is isotropic and homogeneous and obeys Hooke's law,
- friction in all hinges is neglected and gravity is not observed.

2.2 Finite Element Analysis

To investigate the static structural deformation of a spring clip, the finite element method (FEM) is well-suited. Using the software package ANSYS® Workbench 14.5, it is easy to handle a large number of analyses with different analysis settings, element types, boundary conditions, displacements of one joint and deflections of the spring clip. Despite all simplifications modeling the spring clip mechanism by elastic 3D-beam elements (*beam4*) to apply the Euler-Bernoulli theory will produce wrong results, because of the restrictions of infinitesimal strain and small rotations. Instead we have to use a 3D-solid tetrahedron element with a linear element shape function, the solid 185-element and large deflections have to be enabled in analysis settings. Only this non-linear approach generates useful results for the force-deflection behavior of the spring clip mechanism. The hinges A and B are modeled as joints with a rotational motion around the z-axis and the displacement is applied to the hinge B along the y-axis. Subsequent to this first load step the free end of the spring clip will deflect and the force reaction at one point of the free end is analyzed. Figure 2 visualizes the described FEM model and the parameters.



length leg 1	$l_1 = 5$ mm
length leg 2	$l_2 = 1$ mm
length leg 3	l_3 variable
diameter	d variable
Young's modulus	$E = 206$ kN/mm^2
shear modulus	$G = 78$ kN/mm^2

Fig. 2 FEM model for analyses of an asymmetrical spring clip mechanism and parameters (Hartmann and Zentner 2013)

The length of leg 3 is $l_3 = 4$ mm and $l_3 = 3$ mm to investigate the effect of asymmetry of the spring clip to the force-deflection behavior. Diameters of the wire are $d = 0.2$ mm and $d = 0.4$ mm to ascertain its effect on the force-deflection behavior. Fixing 0.2 and 0.4 mm for the displacements of hinge B and the imprinting the maximum deflection (same value as the resulting deflection due to displacement of hinge B but in the opposite direction) in the second load step the force-deflection behavior of the mechanism for different displacements is evaluable.

3 Results

Firstly, the deformed shapes of asymmetrical spring clips without a displacement of hinge B are presented in Fig. 3. The maximum imprinted deflection at the tip is ± 1 mm and all legs are nearly straight. According to the deformed shapes the force reactions at the tip are evaluated. The force-deflection behavior is non-linear, in consequence the spring rate is not constant. If there is no imprinted deflection on the tip no force is generated. Deflection and force reaction go into opposite directions, meaning that a positive deflection causes a negative force reaction. Finally, increasing the diameter of the wire offers higher forces.

Applying a displacement at hinge B in negative y-direction causes a resulting deflection of the spring clip also in negative y-direction. In the case of a nearly symmetrical spring clip ($l_3 = 4$ mm) this deflection of the center tip point is

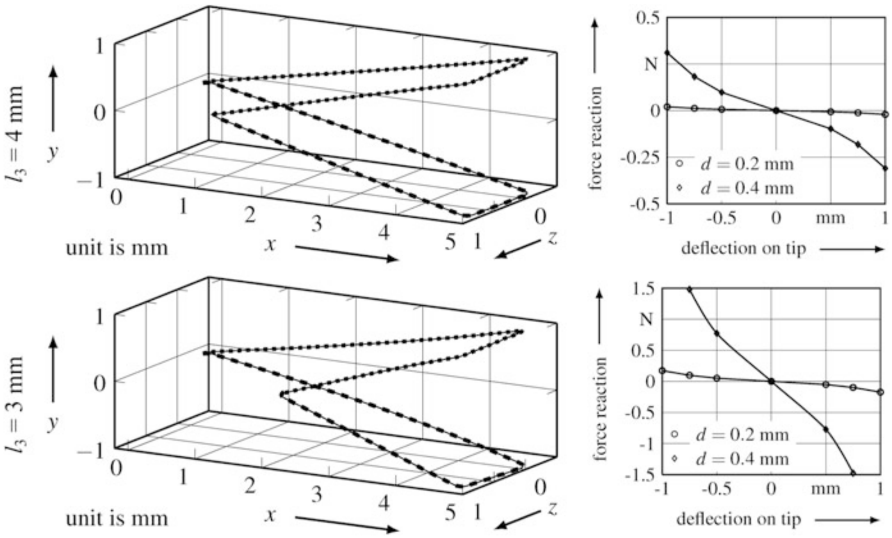


Fig. 3 Deformed shapes and force-deflection behavior without any displacement of hinge B; *left* – deformed shapes of spring clip; *right* – force-deflection behavior

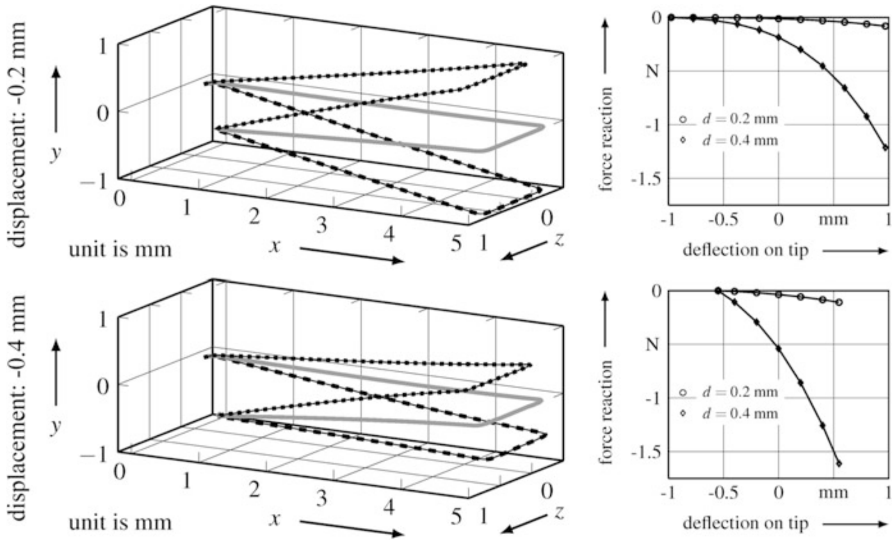


Fig. 4 Deformed shapes and force-deflection behavior with displacement of hinge B for $l_3 = 4$ mm; *left* – deformed shapes of spring clip; *right* – force-deflection behavior

−0.97 mm for a displacement of −0.2 and −0.55 mm for −0.4 mm. The dashed lines in Fig. 4 show this state, where no force reaction is generated. Deformed shape of the clip for an imprinted deflection bringing the tip center point to $y = 0$ is represented by the gray lines in Fig. 4. The dotted lines in Fig. 4 characterize the deformation, if the center tip point is moved to $y = +0.97$ mm or +0.55 mm, depending on the displacement of the hinge B. Contrary to the expectation the minor displacement of hinge B effects a larger deflection than the major one. Again the force-deflection behavior is non-linear but for a deflection $v = 0$ there is a force reaction. The force increases for higher imprinted deflections and major diameters.

According to Figs. 4 and 5 illustrates the effects for a more asymmetrical spring clip ($l_3 = 3$ mm). As expected, major displacements of hinge B realize higher resulting deflections than miner ones (see dotted and dashed lines in Fig. 5). For major displacements and large imprinted deflections the legs are not straight anymore. The force reactions in this case are high in comparison to the nearly symmetrical cases.

In all cases the trajectory of the points of leg 2 is nearly a circular arc in *x*-*y*-plane. The mechanical stress is low due to the rotation of the leg 1 and leg 3 around the *z*-axes. But for major displacements of hinge B and short leg lengths l_3 it will raise due to increasing bending and torsion torques. If the imprinted deflection is too large, bending around *y*-axis has more and more influence on the deformation and the shape deflects to positive *z*-direction (site of shorter leg 3).

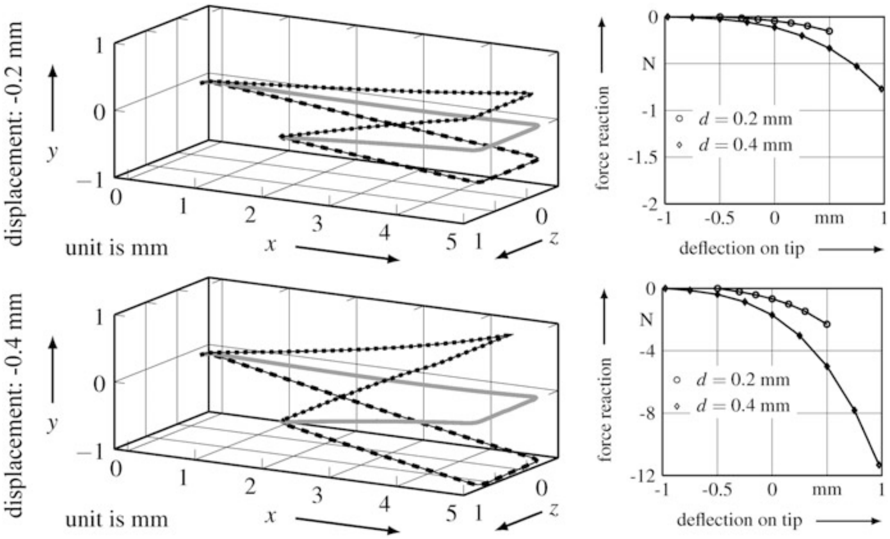


Fig. 5 Deformed shapes and force-deflection behavior with displacement of hinge B for $l_3 = 3$ mm; *left* – deformed shapes of spring clip; *right* – force-deflection behavior

4 Discussion

The results presented in chapter "New kinematic designs of flexure hinge based 3 DoF translational micromanipulators" show that the shifting of the axes (displacement of hinge B) and the asymmetry of a spring clip mechanism influences the force-deflection behavior. In all cases we looked at, the force-deflection behavior is non-linear. Changing the geometry and material parameters of the spring clip mechanisms other force-deflection behaviors can be achieved. Especially for a non-constant wire diameter over the arc length of all legs the spring rate is adjustable. Finally, the wide range of motion, the spring capability and the adjustable spring force are advantages for precision engineering applications. To realize a rocker arm with an angular motion the leg 3 as output element is preferred because of the low bending deformation.

There are several forms of spring clips for specific applications in precision engineering. Using spring clip mechanisms as rocker arms with spring capability reduces the number of parts because of the integration of lever and spring. Of course scaling the geometry and miniaturization of such mechanisms to adapt them to special applications is possible and their manufacturing is easy. Figure 6 visualizes some applications for these mechanisms.

Generally, solving the problem is not trivial even if the modeling seams to offer the usage of a linear theory. Due to the large deflections this highly non-linear problem can be solved by the finite element method but also with some restrictions. To reach a convergent solution and acceptable results the FEM model has to be well adapted at real environmental conditions.

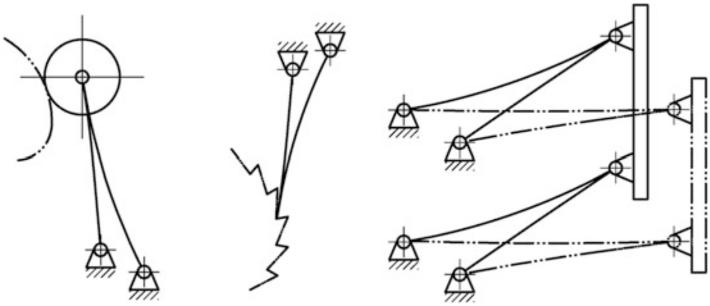


Fig. 6 Application of spring clip mechanisms in precision engineering; *left* – cam mechanism with spring clip mechanism as rocker arm; *center* – spring clip mechanism as pawl in a ratchet mechanism; *right* – parallel spring with a wide range of motion due to spring clip mechanisms

5 Conclusions

A spring clip mechanism with shifted hinges was analyzed using the finite element method. The shifting of axes (displacement) has an influence to the force-deflection behavior. Because of the integration of functions – rocker arm with spring capability – these compliant mechanisms establish new precision engineering applications.

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