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DISPLACEMENT AMPLIFYING SYSTEMS

Tatiana Kelemenová
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, Kosice, Slovak Republic, tatiana.kelemenova@tuke.sk
Miroslav Dovica
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, Kosice, Slovak Republic, miroslav.dovica@tuke.sk
Peter Sedlačko
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, Kosice, Slovak Republic, peter.sedlacko@tuke.sk

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Abstract: Actuator is a part of mechatronic product and low stroke actuator are frequently used mainly in small dimension mechatronic product. Low stroke actuators include piezoelectric actuators (PZT), magnetostrictive actuators (GMA), shape memory alloy actuator (SMA) etc. These actuators have higher efficiency in small scale dimensions than electromagnetic actuators, but these actuators has lower stroke. This problem can be solved via using of amplifying system. Paper presents possible way of amplifying system and application of these systems.

1 Introduction

Evolution in area of mechatronics leads to miniature mechatronic products. It is possible to say, that almost every product are mechatronic. Micro mechatronics is the synergetic integration of mechanical, electronic and control systems based on scaling effects in the micro world. In this time the micro mechatronics and MEMS products are very often used in almost every product around us. Very often it is not visible, but it is included in cameras, mobile phones, microwave oven, photocopier, washing machine, CD and DVD players etc.

Developing of miniature mechatronic products requires also smaller sensors, actuators, mechanisms and electronics. Actuators are key problem in miniaturization of mechatronic products. Selection of the actuators and sensors in area of mechatronics is limited with their dimensions and efficiency. Actuators as piezoelectric (PZT), shape memory alloy (SMA), giant magnetostrictive alloy (GMA) etc. which are applicable in mechatronics systems, have small displacement (several microns) but they have a lot of force potential (hundreds of Newtons). Mechatronics area includes a lot of applications, where much higher displacement is needed. In these cases, "displacement amplifying system" have place for using. Displacement amplifying system, also called as enlarging system, is described as transformation system, which is able to transform input mechanical energy (small displacement and high force) to output mechanical energy with desired parameters (higher displacement and lower force) [1].

The problem with displacement amplifying is also coupled with area of metrology. It is possible to meet with measuring equipment's for small displacement sensing (measurement of geometric deviations of dimension, measurement of geometric shape and position, measurement of roughness etc.) These applications use only transformation of information about small displacement. Different situation is in case of piezoelectric actuator (with diameter 8 mm and length 20 mm). Its blocking force is 1500N and displacement is only 30μm and this combination is not suitable for almost mechatronics application. It is necessary to enlarge the small displacement. The displacement amplifying causes force decreasing. Consequently, it is necessary to use displacement amplifying system for power transformation. These systems are also called as "displacement amplifier" [1], [2], [3].

The aim of this paper is to introduce taxonomy of displacement amplifying systems from the viewpoint of physical principle, which is useful in mechatronics systems.

2 Displacement Amplifiers

There are a lot of displacement amplifiers, which can be divided into these main groups:

- displacement amplifiers based on mechanical principle,
- displacement amplifiers based on fluid principle,
- another displacement amplifiers for indication purposes (aerodynamics principle, pneumatic principle, optical principle, electrical principle) etc.

Displacement amplifiers based on mechanical and fluid principle are classified from the viewpoint of used principle and type of transformation medium for displacement:

1. Levers
2. Flexure bridges

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3. Gears and friction gearing for displacement amplifiers.
4. Displacement amplifiers with deformation parts.
5. Hydraulic displacement amplifier.
6. Inchworm motors
7. Ultrasonic traveling – wave motors

It is not fixed dividing. It shows only on possibilities how to solve problem with displacement amplifying. Specific solution could be also designed as system created from combination of mentioned displacement amplifier types otherwise it could be only analogy to the mentioned types.

3 Levers and Flexure Bridges

Levers are mechanisms which depend on distance ratio between joints and high transverse stiffness of lever. Principle of lever is shown on Figure 1 [1], [2].

Levers bring the simplest form of displacement amplifying. Advantage of lever using lies on practical applicability (there is no fluid leakage).However, levers are need very high production precision. Many parts in stage lever mechanisms bring another resonance frequency to the system. These facts cause problems in many mechatronics application [2].

Flexure bridges are gripped with quasi pin – jointed and depend on longitudinal stiffness of parts. This property causes more compact design than levers (Figure 2).

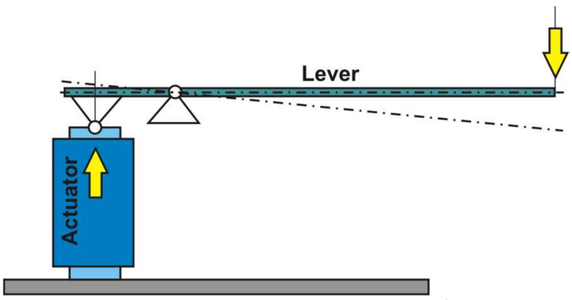

Figure 1 Lever displacement amplifier

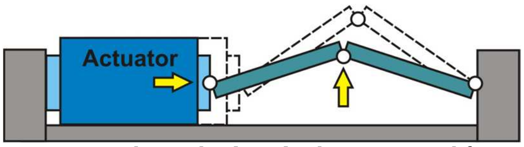

Figure 2 Flexure bridges displacement amplifier

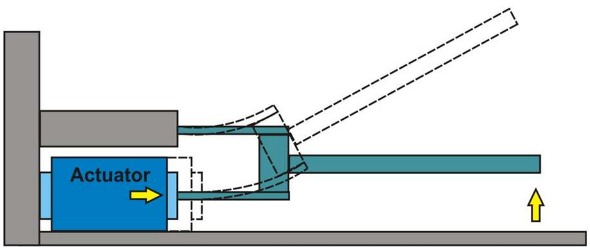

Figure 3 Levers with leaf springs

Levers and flexure bridges can be designed as rigid body mechanism with conventional joints or as compliant mechanisms with spring joints. Many mechatronics applications contain compliant mechanisms with spring joints, because conventional rigid bodies and bearings cause several problems. Application of spring joints brings the desired backlash free motion, which is needed for small displacement actuators [3].

Displacement amplifying is also possible to realize via using levers with short leaf springs (Figure 3). This way of displacement amplifying allows amplifying displacement 300×. This way is very often used in projection microscope [1], [2], [3].

Spring joint (Figure 4) is rotation coupling with limited angle of rotation. They are very often used in equipment's because of their many advantages:

- no friction and other passive resistance,
- backlash free motion,
- do not need lubricate and service,
- insensitive on dirties,
- wear resistance.

The main disadvantage of spring joint is their dependence of rotation axis on applied forces. Deformation of the spring joint needs another additional energy, which is accumulated inside spring joint. It causes loss in deformations and part of energy dissipates to heat energy. These facts decrease efficiency of system.

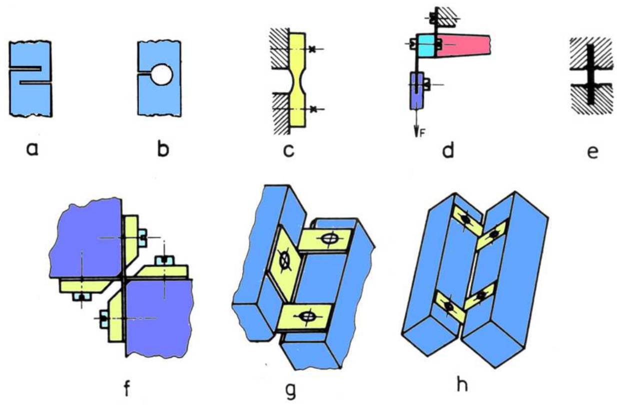

Figure 4 Example of spring joint

4 Displacement Amplifiers with Deformation Parts

Deformation of low stiffness parts is also useful for displacement amplifying. These low stiffness parts can be made as perforated ribbon, which is twisted and pulled in marked direction (Figure 5). It causes rolling and unrolling of ribbon coupled with indicator pointer. This way allows amplifying small displacement with very high precision without backlash (indicator for measurement of geometric deviations).

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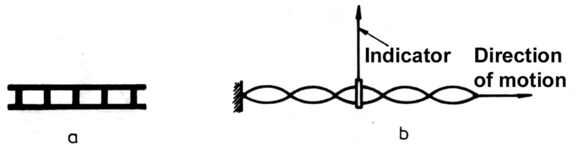

Figure 5 Displacement amplifier with deformation part

5 Gearing and Friction Gearing for Displacement Amplifying

Problem with displacement amplifying can be also solved with combination of lever and gearing (Figure 6 left). The main disadvantage of this solution is backlash between gears. Another way is using of friction gearing (Figure 6 right), but slipping can be occurs in this solution.

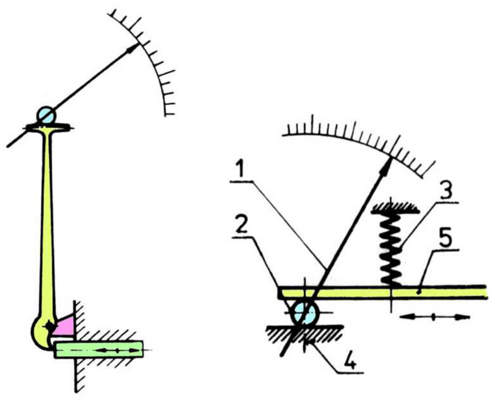

Figure 6 Gearing and friction gearing for displacement amplifying

6 Hydraulic Amplifying Systems

Using of elastic medium (rubber, fluids like oil or water) is suitable solution for displacement amplifying. Fluid behaves as non-compressible medium. This property is main advantage for using in displacement amplifying system (Figure 7) [2].

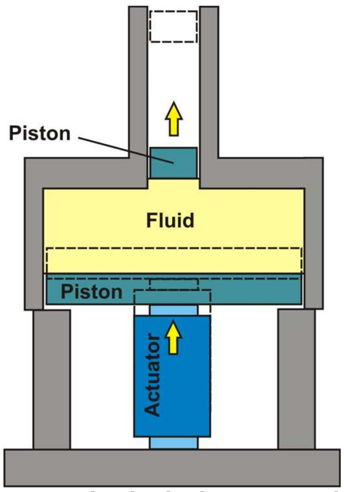

Figure 7 Hydraulic displacement amplifier

The hydraulic displacement amplifier allows bigger place for flexibility of design and lower loss caused with deformation of amplifier structure. Marginal problem occurs in chamber sealing to avoid the fluid loss.
Dynamic behaviour of hydraulic displacement amplifier is determined with time needed for wave transition through the transport medium (fluid) [2].

7 Inchworm Motors

The term „Inchworm“ is registered trademark of Burleigh Instrument, Inc. and it is used as name for structure (Figure 8), which generates motion via using of conception based on three piezoelectric actuators (also called as PZT). Suitable configuration and control algorithm allows the amplified motion against the one piezoelectric actuator. Although it has amplified displacement, it has also extremely high mechanical resolution (about 4 nm) [4].

The term inchworm comes from biological inspiration from biological pattern called with the same name “inchworm”. Principle of the motion is based on three PZT actuators placed on guiding rod. Two actuators place on edges are called as clamp actuator. Middle piezoelectric actuator is able to change distance between both clamp actuators. Suitable designed algorithm of actuator exciting causes forward motion on guiding rod.

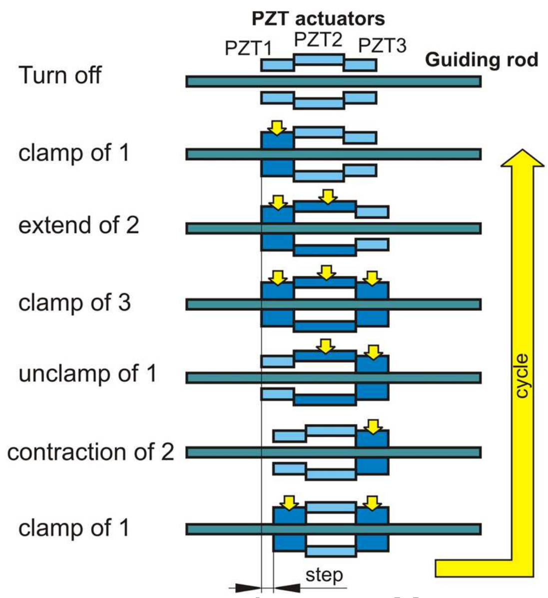

Figure 8 Inchworm motor [4]

Inchworm motors with ultra-high resolution are made as various versions with resolution from 1 nanometre (10-6m) to 2,5 angstroms (2,5.10-10m) , what is relative to atom size. These properties are used as positioning systems in raster microscopes [4].

8 Ultrasonic motors based on traveling wave

Ultrasonic motor converts ultrasonic mechanical energy to mechanical energy via friction force between the sliding segment and stator. This type of the motion is called as traveling wave. The principle of the ultrasonic motor is described on Figure 9 [5].

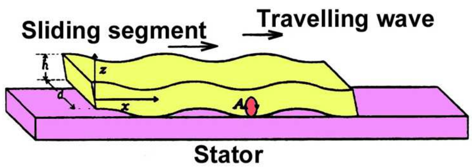

Figure 9 Principle of the planar ultrasonic motor [5]

Traveling wave traverses through these every elements of surface on the sliding segment and consequently these elements move on elliptical trajectory. If any object will be in contact with the segment, then this object will move through the friction force effect generated between them. Principle of the motion in ultrasonic motor has analogy in surf plate moves on sea waves. The ultrasonic motor has several advantages. It has compact design and it has still force also without exciting. It has bigger torque also in low motion speeds. The main disadvantage is requirement of high frequency power supply [5].

Principle of the rotation ultrasonic motor (Figure 10) is the similar to the planar ultrasonic motor. Rotation ultrasonic motor is very often used in cameras for focusing in objective [6].

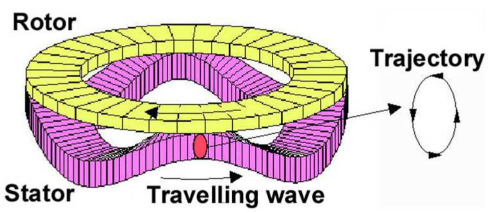

Figure 10 Principle of the rotation ultrasonic motor [6]

9 Application of actuators with displacement amplification

Inchworm principle is very often applied as locomotion principle for in-pipe machines (Figure 11). Original principle is modified, because pipe wall is instead of previous guiding rod. Fast repeating of inchworm strategy enables the in-pipe locomotion. Clamping module has low stroke and another amplification principle is necessary for this reason. Also it could be problematic if any pipe wall geometric deviation, sediments on inner wall or pipe wall deformation occurs.

Another solution of clamping module is used in another in-pipe machine (Figure 11).

Contact of machine with inner pipe wall is ensured via using of elastic bristles, because they enable better adaptation to inner pipe wall irregularities. Clamping function of bristles is ensured with amplifying system, which consists of flexible joint levers. Figure 12 shows simulation of displacement amplification function of designed compliant system.

Piezoactuators with traveling wave ultrasonic motor are frequently used for camera focusing, because of small dimension, small weight and very good efficiency.

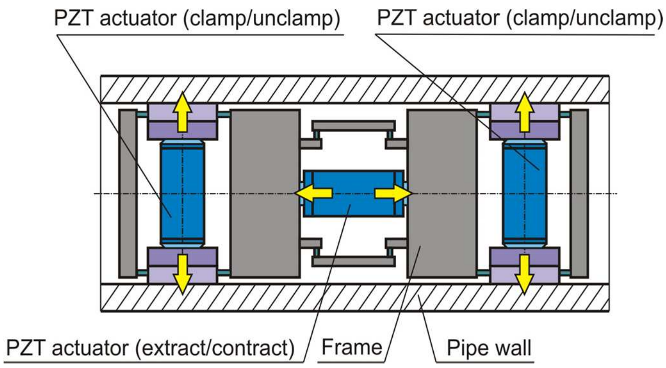

Figure 11 Inchworm principle applied to in-pipe machine locomotion

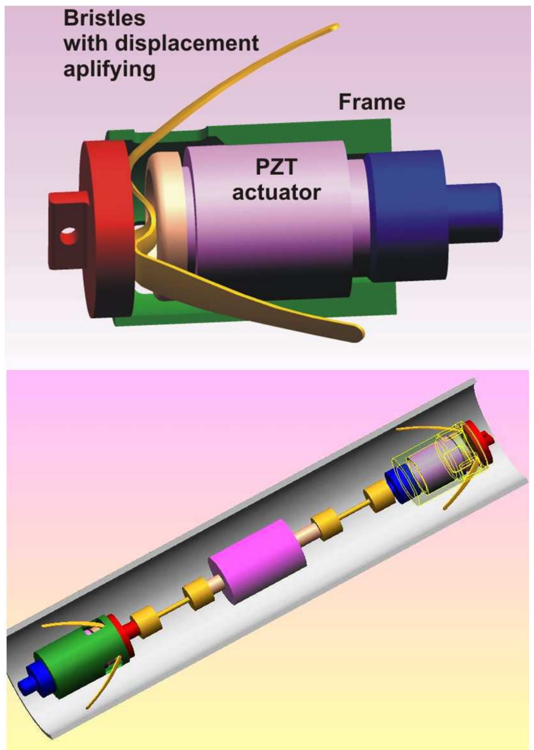

Figure 12 Miniature bristled in-pipe machine with displacement amplified PZT actuator

10 Conclusion

In this paper we introduced the displacement amplifying system used in mechatronic products. Miniaturization plays key role in developing of mechatronic products. Because of scale effect of actuators, unconventional actuators (PZT, GMA, SMA etc.) with low stroke are very often used. For this reason it is necessary to develop and use the displacement amplification system [7], [8], [9], [10].

Acknowledgement

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