Available online at www.ijapie.org

INTERNATIONAL JOURNAL OF ADVANCED PRODUCTION AND INDUSTRIAL ENGINEERING

IJAPIE-2018-01-122, Vol 3 (1), 05-10

IJAPIE
Connecting Science & Technology with Management.

A Journal for all Products & Processes.

Non-Conventional Actuation Mechanisms used in Mechatronic systems

Rajiv Chaudhary[1], Alok Kumar Singh[2]

([1]Mechanical Engineering Department, [2] Electronics & Communication Engineering Department, Delhi Technological University, Delhi, India)
rajivchaudhary@dce.ac.in, aloksingh.dce@gmail.com,

Abstract : Tracking the path of development in different Engineering disciplines, it can be easily observed that, right from the primitive stage, several tools, devices and techniques may be identified, which happened by virtue of evolution of human intelligence, getting transformed into various engineering applications. Although, later different engineering disciplines evolved, where most of the exhaustive development could be undertaken in that discipline. Likewise, in the field of mechanical engineering too various types of mechanical systems, according to the requirement in that field, were developed, in order to providing support of mechanization. Prime movers used to be an important part of these mechanical systems, which provided energy input as well as actuation required for providing the machines the desired kinematics. Most of the mechanical systems developed has been operated by conventional engine system using one or other fuel. Apart from the actuation by mechanical means, there are other means also through which mechanical actuation with better control, flexibility and manipulation may be utilized in mechanical systems. A different category of systems, called Mechatronic systems has been developed in recent past, which involves vivid scope of use of techniques, devices and components generally used in various other engineering fields of electrical, electronics, hydraulics and pneumatics etc. Subsequently, there has been several inventions, design & development which have added new levels in every field. Mechanical systems have been generally composed of various mechanical elements, which are designed to follow certain kinematics. Performance of the Actuation system plays an important role in overall performance of the mechanical systems. There are several alternative actuation systems, which are not mechanical. These actuation systems may be categorized into electrical, electronics, hydraulic and pneumatic type. The features of these actuation systems, are so peculiar, that typical kinematic movement may be manipulated that to with more precision. Better control of mechanical systems may be realized, which is otherwise difficult with mechanical systems. In this paper, an effort has been made to review the possibilities, prospects as well as scope with various actuation systems.

Keywords: Actuation system; Mechatronics; Mechanical systems; Control.

I. INTRODUCTION

Completing the period of mechanization in last century, and subsequently collaborating with other emerging new engineering fields various new domains have commanded their position in current situation. Mechatronics is one such field emerged by collaborating the field of mechanical engineering with the field of information technology, electronics as shown in Fig1.

With advent of this new field one another philosophy of design has emerged called Mechatronic Design Systems. If we compare this new Mechatronic system concept with conventional one then we find that the old one to be bulky, because of many components and mechanisms connected together. Analog control, lack of flexibility, arbitrariness in the system due to uncertainties further make the system stiff. While, the new Mechatronic Design Systems are Compact, having simple mechanisms,

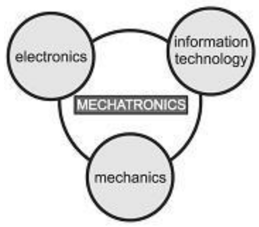

Fig 1. Mechatronics: Synergetic Integration of Different Disciplines.

involving wireless communication and autonomous units along with integrated with information processing for smart and intelligent control of the systems. Out of various essential components of mechatronic systems, actuators are very important part of the system.

II. ACTUATION SYSTEMS

The Actuation systems are the physical devices meant for transforming various forms of energy i.e. electrical, hydraulic, chemical or thermal energy into mechanical output. Actuation systems are actually the parts of a control systems of any mechanical systems, which transforms the output of a microcontrollers/microprocessor controlled systems, in order to achieve a certain kinematic action of a mechanical system.

There may be many types of actuation systems, based on using different types of energies. These systems have been discussed here with their respective kinematic suitability to the mechanical systems under different desired conditions. Actually, there may be many ways the actuation systems may be classified. One such basic criterion on which classification of actuators may be made is the basis of type of motion in terms of steps or continuous motion. These may be called incremental motion type or continuous motion type actuators respectively. But most of the actuators in mechatronic systems belong to category of continuous-drive devices, like DC Motors, AC Motors, Hydraulic and Pneumatic motors, and piston-cylinder drives (rams).

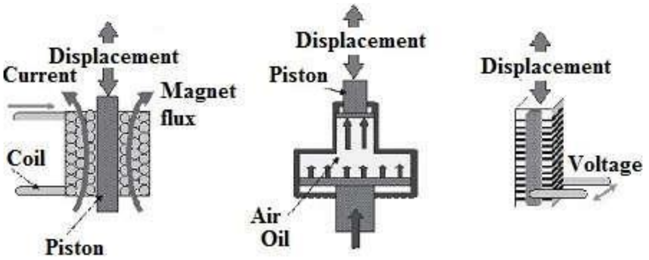

Fig 2. Mechanisms of various Actuating systems

A. Electrical Actuation systems

These systems have been developed, which are based on electrical as well as mechanical principles. These primarily consist of electrical motors, however, some other types, like solenoids also have been used as electrical actuators. A wide variety of motors is available today, bearing suitabilities to various situations, according to performing different tasks, as different motors exhibit different characteristics. These became popular because of their simple and easy operation. In comparison to other systems these systems are cheaper, easily available and can be integrated to most of the systems ensuring its proper control.

A1.Electric Motors:

Every motor has a moving component called Rotor, a stationary component called stator and a covering and containing the whole unit called Housing. Electric motors are actually the most popular electrical actuation systems. Motors are the devices used for converting electrical energy into mechanical energy, which ultimately produces mechanical output in form of Torque and Speed, by using input in form of voltage and current. Based on the mechanism of conversion there different types of motors.

A1.1 AC Motors:

Alternating current is supplied to the stator winding in AC motors. These are either synchronous (Rotor of permanent Magnet) or asynchronous type (Rotor as simple close loop conductor) induction motor. By varying the signal frequency the speed of the AC motors may be controlled as the speed of AC motor depends on input signal. AC motors run on an alternating current supply made to the stator windings. These motors work under two magnetic field. The first magnetic field is developed by the excitation current on the stator. This magnetic field develops current in the rotor, following which another magnetic field is developed. For producing maximum torque per unit current, these two magnetic field vectors are kept perpendicular.

A1.2 DC Motors:

DC motors run on DC power supply. In DC motors the stator magnetic poles are either produced by a permanent magnet, which has been generally found suitable with small motors, or through stator winding.

The DC motors work under two magnetic fields, the magnetic field developed due to the current through the armature winding on the rotor, and another due to the permanent or electromagnet used in the stator. Depending upon the respective roles of stator and rotor further there are two types of DC motors. Brush type and Brushless type DC motors. By controlling the Voltage supplied the speed of the DC motor may be controlled, but for motors with stator windings, speed control may be done by varying the current also. Standard DC motors with brush face a problem of brush wear. In brushless motors the brush and commutators are omitted, which increases the reliability.

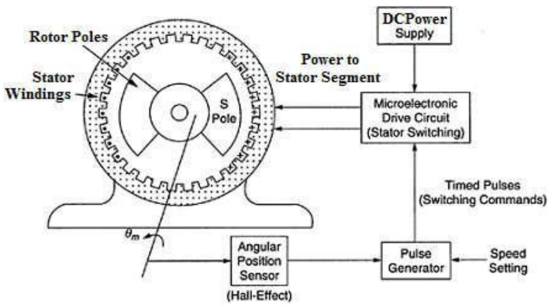

Fig 3. System of Brushless DC Generator

A1.3 Stepper Motors:

Stepper motors are incremental motion type actuators which move in certain angular steps, as set. It may be also considered as digital actuators, as these are pulse-driven devices, which provide certain predetermined angular motion in steps according to number of pulse received. These are brushless and permanent magnet type DC motors, which are used when incremental motion is required. A stepper motor possesses the ability to move a specified number of revolutions or fraction of a revolution in order to achieve a fixed and consistent angular movement. There are various types of Stepper motors, like Variable Reluctance step motors, Permanent Magnet step motors and Hybrid step motor. These are used in small to medium industrial applications, which is digitally controlled without any feedback. With stepper motors more accurate and precise

motion becomes possible, as it ensures fractional elemental increment of shaft rotation corresponding to each pulse. Its use is easy, cheaper and it is effective in open loop systems.
It is more suitable in situations where, lower torque capacity, with limited speed is required. In such applications it is important to avoid pulse missing, which otherwise causes large vibrations as well as errors.

A1.4 Servo Actuation system

Sometime, in spite of using single actuator, we use combination of drives in order to make manipulatory control of the system like in robotic control. These are called process actuators, which are often applied to perform the final control function. These actuation systems are called as control actuators. Servo Actuation system is one such systems, in which actuators sense the error signals through feedback, if any, and correcting the operation of the process.
For accomplishing this function, servomotors are used,in which it senses, the position, its speed, torque as well as produced current to operate the mechanism.

As in a Optical Disk Drive, accurate positioning of laser spot within the range of micron is required. With servosystem, this positioning with desired accuracy may be done, and movement from any track to any track also can be done when required. With servosystems this also becomes possible to move across the whole disk surface, otherwise it would be a larger system with its inherent limits of response as well as reduced accuracy.

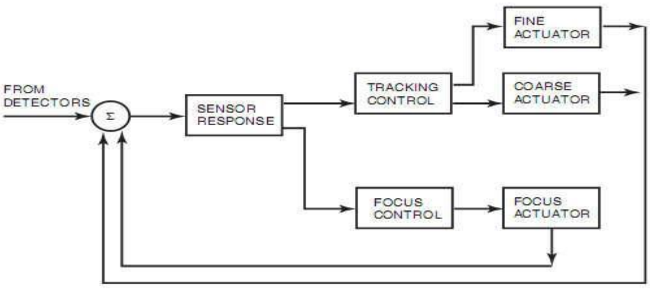

Fig 4. Block diagram of the servocontrol system for an optical disk drive.

A1.5 Electrostatic Motors:

Contrary to the conventional electric motors, which use magnetic force, the Electrostatic motors use the phenomenon of attractive and repulsive forces between the electric charges. Electrostatic forces have been found very suitable for such Micro-machines. One this type of electrostatic motor has been shown in Fig 5.

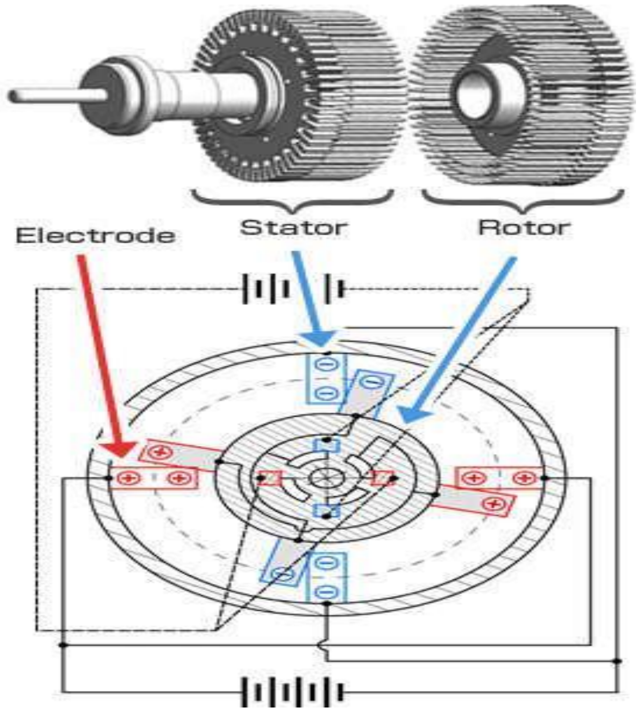

Fig 5. Arrangement of Electrostatic Motor (Shinsei Corporation Japan)

A1.6 Micro- and Nanoactuators

There is a category of actuating systems, involving components of very small size, called microactuators, which are able to produce motions as well as forces at micro level. Developing such systems need more attention as conventional methods of design and analysis may not be applicable. Due to the reasons, sometime, such actuators are developed using special materials and techniques, considering these specific requirements.Under it micro-machines are developed by fabricating systems using actuators or the functional parts of sizes not more than 15 mm. These are also called Micro-Electro-Mechanical system (MEMS).

A2.Torque Vs Speed characteristics of an Electric motor:

Electric motor can act as a device for producing mechanical power (as motor), or it can also act as generator while running reverse externally (as generator). Then the Torque and Speed under different conditions may be expressed on steady state torque versus speed plane, as shown in the following figure Fig 6.

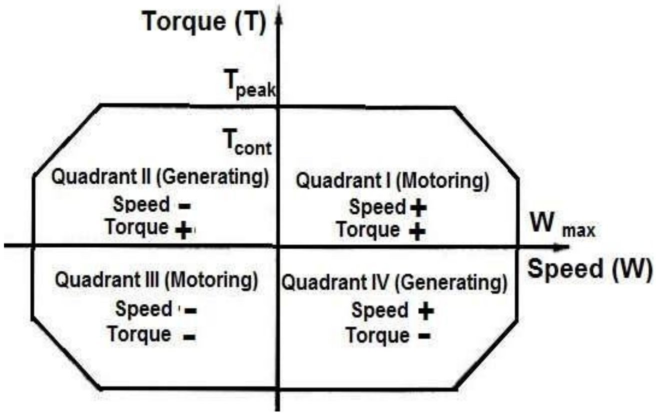

Fig 6. Torque Vs Speed characteristics of an Electric motor.

A3.Torque developed in a Motor:

By conversion of Electrical energy into Mechanical energy, in a motor, the mechanical power developed in form of torque may be seen as a consequence of interaction of those two magnetic flux density vectors of stator as well as rotor. The value of the Torque may be expressed in term of the strength of the two magnetic flux density vectors and the Sin of the angle between two magnetic flux density vectors. This relationship can be expressed in the following way,

$$T_m = K.B_r.B_s.\mathrm{Sin}(\theta_{r.s}) \quad (1)$$

Where,

Torque developed $= (T_m)$

Magnetic flux density vectors of rotor $= (B_r)$

Magnetic flux density vectors of stator $= (B_s)$

Angle between Magnetic fields $= (\theta_{r.s})$

and K is a constant of proportionality, whose value depends on motor size and design parameters.

B. Electronic Actuation systems:

By inclusion of the principles of electronics with mechanical systems the overall process assessment and control became possible. By involving digital logic, logic gates, along with combinational as well as asynchronous & synchronous sequential logic, design of logic system became possible, which made the systems smarter. Incorporation of communication systems, provided a tool to get the status of the process any moment and make intermediary adjustments. Due to this, fault detection became possible. Use of microcontrollers, microprocessors programmable logic controllers and computer architectures, by incorporating these into the design itself the system became intelligent.

C. Pneumatic Actuation systems:

These systems generally make use of pressurized air or gas for generating power. It is extensively used in the field of manufacturing, particularly in automated assembly section. Apart from the mounting of Pneumatic Actuation systems being easier, these systems are much simpler, easier and lighter in comparison to motors. These systems are shock resistant and these may be operated with great durability and lesser chances of damage. It may maintain constant force, however, it is suitable for the linear motion. One such of Pneumatic Actuation system (cylinder) has been shown in Fig.7

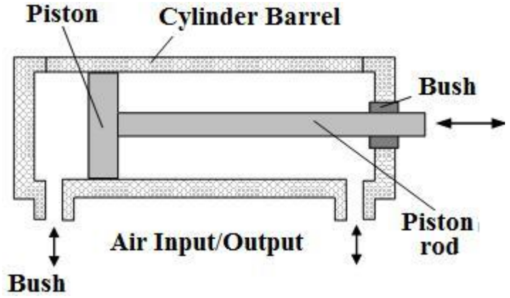

Fig 7. Pneumatic Actuation system (cylinder)

D. Hydraulic Actuation systems

In this type of hydraulic actuation system, some fluid (e.g.Oil), under pressure, is supplied by a pump, which is driven by an electrical motor. The pressure of this fluid is utilized for the actuation system. As shown in the figure 4.0 the oil is pumped to the system to be operated, from a sump through a non return valve and an accumulator, from where it ultimately returns to the oil sump. The accumulator takes care of the fluctuations in the oil pressure in the supply line, in order to ensure smooth supply of oil. One such of Pneumatic Actuation system (cylinder) has been shown in Fig.8

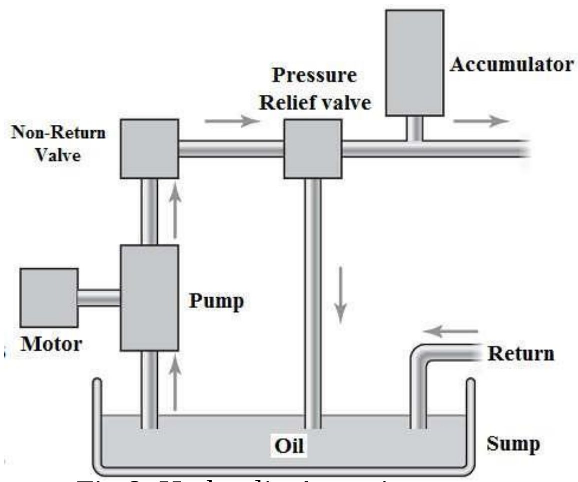

Fig 8. Hydraulic Actuation system

E. Piezoelectric Actuation systems:

These devices make use of the reverse piezoelectric effect. Because, piezoelectric effect is actually the generation of electric charge because of the application of mechanical force over some piezoelectric material. As shown in the following figure, for example, on application of 1,000 voltage to a piezoelectric ceramic plate of thickness of 1mm (in the electrical field of 1,000V/mm), a displacement of about 1μm has been acquired due to the reverse piezoelectric effect. It is a device which features high displacement accuracy. The degree of force generation and level of response speed are also high. It is suitable in industrial applications where precise position control is desired. Application wise the field of compact electronic gazettes/equipments such as cell phones and digital devices etc is finding great favor with these systems. In Fig 9. Piezoelectric and reverse Piezoelectric effect has been shown.

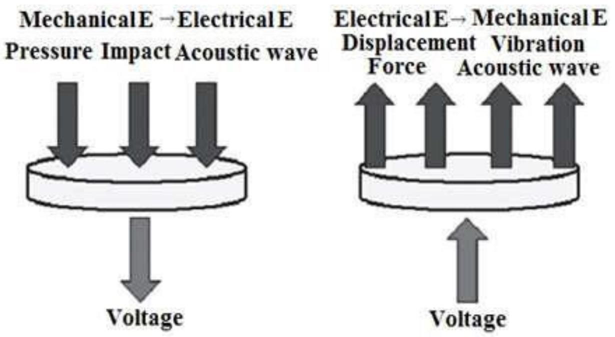

Fig 9. Piezoelectric and reverse Piezoelectric effect

III. KINEMATIC REQUIREMENTS OF ACTUATION SYSTEMS.

A. There are variety of kinematic movements which are required in machines. Important kinematic movements may be mentioned as mentioned below.

1) Plane motion: When the motion of a body is confined to only one plane.

2) Rectilinear motion: When the motion of the body is along a straight line. Reciprocating motion may also be considered under this type of motion.

3) Curvilinear motion: When the motion of the body moves along a curvature. Rotary motion is a particular type of Curvilinear motion.

4) Translatory motion: It is studied when the motion of a body is under consideration. Further, it may be either Rectilinear Translation or Curvilinear Translation, depending whether under Translation the motion is Rectilinear or Curvilinear.

5) Continuous: Sometimes the machine is under requirement of continuous motion while running.

6) Intermittent: Sometimes the requirement of the motion may not be continuous, rather Intermittent, as per the actuation requirement of the machine.

7) Irregular Geometry based motion: Sometime the motion required may be of some typical geometry for which motion may be controlled with help of microprocessor/microcontroller.

IV. CONCLUSION

Looking into the prospects of various actuation systems we could see that there is availability of a wide variety of actuation systems to apply in some particular situation. With emerging trend of complex systems the type of situation has triggered several kind of operating conditions.

Obviously, control part of these systems have also become specific. So, new techniques and methods have been explored in order to make precise control of speed, movement, torque, energy, for following the desired kinematics. Inclusion of these actuation systems not only have added more options but also these have made the system faster, precise and controllable. Under different working conditions also, be it operational difficulty, problem of control, flexibility issue, or be it problem related to maintenance, or lightness of the system etc, we have got options in various situations. These all the features underlines the importance of the actuation systems and also suggests future prospects in this area. In the table1. a comparison of different actuating systems has been shown.

TABLE1. COMPARISON OF DIFFERENT ACTUATING SYSTEMS

Parameter	**Hydraulic**	**Pneumatics**	**Electrical**
Working Fluid	Mineral Oil	Air	Voltage-Current
Working Pressure	500 Bar (maximum)	6-7 bar	Up to 11kV
Available Force	100kN	10kN	100kN
Speed	Low	High	Very High
Conversion Efficiency	Over 70%	Under 20%	Over 80%
Capital Costs	High	Low	Intermediate
Proportional Control	Easy	Difficult	Easy
Hold Load Power-Off/ Stability	Possible	No (air is compressible)	Possible
Precise Positioning	Easy	Difficult	Easy
Environmental Influences	Sensitive in case of temperature fluctuation, risk of fire in case of Leakage	Explosion proof, Insensitive to temperature	Risk of explosion in certain areas, insensitive to temperature
Energy storage	Limited with the help of compressed gases	Easy	Difficult, only in small quantities using batteries
Linear Motion Simple using cylinders	Simple using cylinders	Simple using cylinders	Difficult and expensive– with motion converter
Rotary Motion	Simple	Simple	Simple

REFERENCES

1. Robert H. Bishop, MECHATRONICS HANDBOOKCRC PRESS © 2002 by CRC Press LLC www.crcpress.com
2. Mamiya Yoichi, Applications of Piezoelectric Actuator, pp 82-86, NEC Technical Journal, Vol 1 No. 5/2006
3. Kyura, N. and Oho, H., "Mechatronics—an industrial perspective," IEEE/ASME Transactions on
4. Mechatronics, Vol. 1, No. 1, 1996, pp. 10–15.
5. Mori, T., "Mechatronics," Yasakawa Internal Trademark Application Memo 21.131.01, July 12, 1969.
6. Sabri Cetinkunt, Mechatronics, John Wiley & sons, 2007
7. Robert H. Bishop, MECHATRONICS : An Introduction, University of Texas at Austin U.S.A.Published in 2006 by CRC Press Taylor & Francis Group.
8. Schweitzer, G., Mechatronik-Aufgaben und Lösungen. VDI-Berichte Nr. 787. VDI-Verlag, Düsseldorf,1989. [9]- Ovaska, S. J., Electronics and information technology in high range elevator systems. Mechatronics,2(1):89–99, 1992. [10]-Fearing, R. S., "Microactuators for microrobots: electric and magnetic," Workshop on Micromechatronics, IEEE International Conference on Robotics and Automation, 1997. [11]-Robert H. Bishop (Ed.), The Mechatronics Handbook, CRC Press, 2000
9. George Rzevski (Ed.), Mechatronics, Perception, Cognition and Execution, Butterworth-Heinemann, 1995
10. W. Bolton, Mechatronics, Electronic Control Systems in Mechanical and Electrical Engineering, 2nd Ed, Longman, 1999
11. D. A. Bradley, D. Dawson, N.C.Burd, A.J.Loader, 'Mechatronics, Electronics in Products and Processes', Chapman & Hall, 1993
12. Jerry C. Whitaker, Microelectronics, CRC Press Taylor & Francis Group, 2006
13. Electrostatic motors: Shinsei Corporation Japan
14. MFE 3004 Mechatronics I "Actuation in Mechatronic Systems.