A Review of Compliant Mechanisms Manufactured by using 3D Printing Technology

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Abstract

3D printing is emerging as a revolutionary manufacturing process for the future. Presently 3D printings are mostly being used in prototyping, but with rapidly changing designs and need of customization it will emerge as new go to manufacturing technology. With its capability to produce complex part easily and new material being developed with high capabilities for 3D printing, we see it being used in advanced application like bioengineering, aerospace, robotics etc. Compliant mechanism is mechanism without any joints, which means entire mechanism is made of one part eliminating joints and thus reducing size of the mechanism. When compliant mechanisms are produced with 3D printing manufacturing becomes convenient and mechanism thus produced finds it application in many areas due to its compact size and reduced number of parts. This paper gives introduction to commonly used 3D printing technology and compliant mechanism, and analysis use of 3D printing to develop compliant mechanism for different application along with their merits and demerits. Different materials used in various applications are also discussed. In conclusion this study suggests many possibilities of application of 3D printed compliant mechanism especially in aerospace and micro-robotics.

Keywords: 3D printing; compliant mechanism; FDM; Additive manufacturing; Monolithic Mechanism.

1. Introduction to 3D printing and compliant mechanism

Nowadays 3D printing is one of the growing technologies in which method of additive manufacturing is used to create three-dimension parts with ease. In additive manufacturing as the name suggests, additive process is used to make parts in which with the help of nozzle it creates bed first and starts its process and after creating successive layers 3D printed parts are manufactured. If one takes cross sectional area of final part then he can observe each layer placed horizontally. In subtractive manufacturing, extra material is removed whereas additive manufacturing is opposite method in which instead of cutting layers are added to form part.

Moreover, with the help of combination of 3d printing and compliant mechanism one can cope up with rapid prototype production, cost issues and properties like flexibility, strength and many more. 3d printing is considered as ideal method for the producing any type of complex compliant mechanism due to its flexible nature. Moreover, Compliant mechanisms obtain its motion from the elastic deformation [1] Compliant mechanism is very helpful in the small-scale robots and with the use of that we can avoid two parts in contact [2]
With the help of compliant mechanism, we can achieve mainly two things Reduction in parts = less weight, Reduce manufacturing complexity [2]
If we take example of 3D printed compliant gripper then compliant part helps to prevent any damage of object which is helpful in material handling [3,4]

Compliant mechanism is easy to produce with 3D printing technology and have found their application in many fields such as robotics, space applications, micro and Nano systems, biomedical engineering etc.

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Fig. 1 3D Printed Compliant Gripper [5]

3D printing will improve compliant mechanisms with lighter materials and new design solutions such as interlocking of parts or hollowing of part body. But most importantly, one can actually design a mechanism that can be fully 3D printed in one piece. The main methods of 3D printing are as follow.

1.1 FDM (Fused Deposition Modelling)

It works by extruding material through a nozzle to print one cross section of an object [6], followed by lowering the platform so that it can continue further for a subsequent layer [7]. Moreover, the initial point of the printer contains type of heating device which liquefies wire as soon as it passes through the nozzle and a new layer is formed. Some important benefits of FDM are inexpensive, lightweight, fast and easy procedure. On the other hand, it also had different limitations like fragile mechanical properties and substandard exterior characteristic [8]. Moreover, it had limited number of thermoplastic materials which can be used as materials [9].

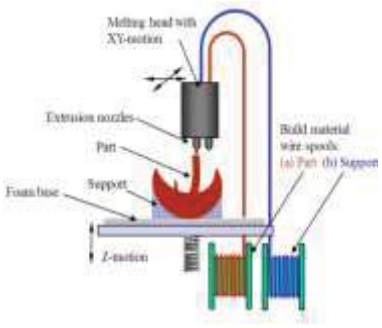

Fig. 2 Fused deposition modelling [10]

1.2 Poly-jet 3D Printing Technique

It is unique type of additive manufacturing process proficient to employ rigid as well as pliable material sectors into a one stop production, making it specially licensed for construction of complex and conglomerate compliant mechanism. It offers true-colour print, with a film width of 16-30 micro meter and obedient design of 42 micro meters [10]. Moreover, here we can combine two materials simultaneously in different proportion to form nine gradient material whisks.

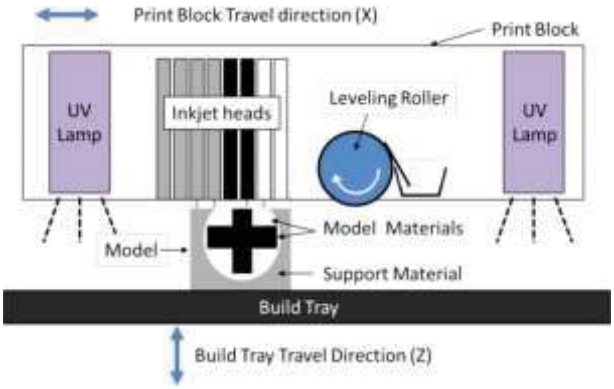

Fig. 3 Demonstration of unswerving 3D Poly- Jet printing method [11]

1.3 Electron Beam Melting (EBM)

Due to drawbacks of FDM method and poly-jet 3d printing and to make complex parts of titanium electron beam melting is created. EBM is type of 3D printing in which metal powder are melted together and with the help of that it makes successive layers [11]. In EBM, Designation of parts is made with reduced manufacturing constraints. With the other types of 3D printing, we are not able to make compliant mechanism in metal form but with the help of this technique we are able to make metal monolithic structure [11]. EBM allows us to make monolithic structure in such way which is not possible by any other method of 3D printing.

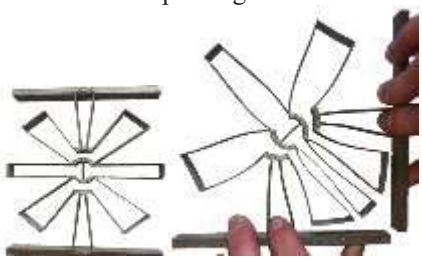

Fig. 4 A Complaint titanium hinge made with EBM. It has efficient of -90* to +90* of movement [12].

1.4 Stereolithography (SLA)

Stereolithography, which was developed in 1986, is also part of oldest practices of 3D printing [13]. SLA builds parts from top to bottom. In this technique UV light or electron beam is imparted on layer of monomer or resin to initiate a chain reaction to create polymer. This one layer of polymer supports the next layer and part is produced layer by layer. It can also print ceramic polymer composite [14,15]. SLA prints true quality components at accurate resolution starting 10 micro meters [16]. On the other hand, it is comparatively decelerated, costly and only few materials are available for the printing. Also, kinetics of the reaction generating procedure is complex. The vitality of light origin and exposure are the key constituent managing the size of particular plane [17].

2. Merits of 3D printing

There are several upsides available for 3D printing from which few are mentioned below.

The main advantage of 3D printing is rapid manufacturing compare to conventional techniques in the result we can save lots of time. Another merit off this technology is rapid prototyping. Nowadays, we all are interconnected across the globe and because of this technology we can make any kind of prototype in rapid mode. Moreover, the amount of cost it takes is very less compare to other methods. Another exciting feature of this method is that we can make object anywhere, it means it does not require heavy investment in production facilities. Nowadays, we are living in the zone where monitoring of pollution matters a lot. So, 3D printing in that matter is pollution free technology

3. Demerits of 3D printing

Since various methods are used to manufacture compliant mechanisms on contrary it also has some drawbacks. This demerit varies from method to method. Mainly, they are dependent on the various factors such as thickness of the prototype, orientation, raster angle, air gap etc. [7]. Although FDM is widely used and cheap method due to layer-by-layer configuration quality of surface is not good compare to conventional method [18]. Moreover, in these techniques stiffness problems arrive because in 3D printing different orientation gets different results [19]. In 3D printing while analysing and characterising, we should not treat component as a material property but instead of that we have to treat them as a structural property [7].

4. Development of compliant mechanism

Development of 3D printed compliant mechanism is based on two domains which are listed as below.
Firstly, that is synthesis methodology which defines desire degree of freedom, high stiffness, large work space, large dynamic response with high frequency. Secondly, fabrication technology defines the performance of complaint mechanism [18].

4.1 Different types of compliant mechanism [20]

- Compliant mechanisms with path generation
- Compliant mechanisms with multiple degrees of freedom
- Compliant mechanisms with multiple physics
- Compliant mechanisms with multiple materials

4.2. Benefits of compliant mechanism over conventional mechanism

Due to elimination of certain factors, it is possible for Monolithic mechanisms to achieve high performance in two or more axis setup [11]. Moreover, there are several other benefits of compliant mechanism which include reduce part count, decrease in the assembly time, less maintenance, comparatively low weight, cost effective and alternative of traditional rigid linkage mechanism [21]. It not only prevents vibration during high speed but also eliminate the requirement for lubrication [22]. Also, complaint mechanism is able to provide the precise motion during its operation [18].

An example of conversion of conventional mechanism to compliant mechanism is given as below from which we can easily define the problem and find the solution.

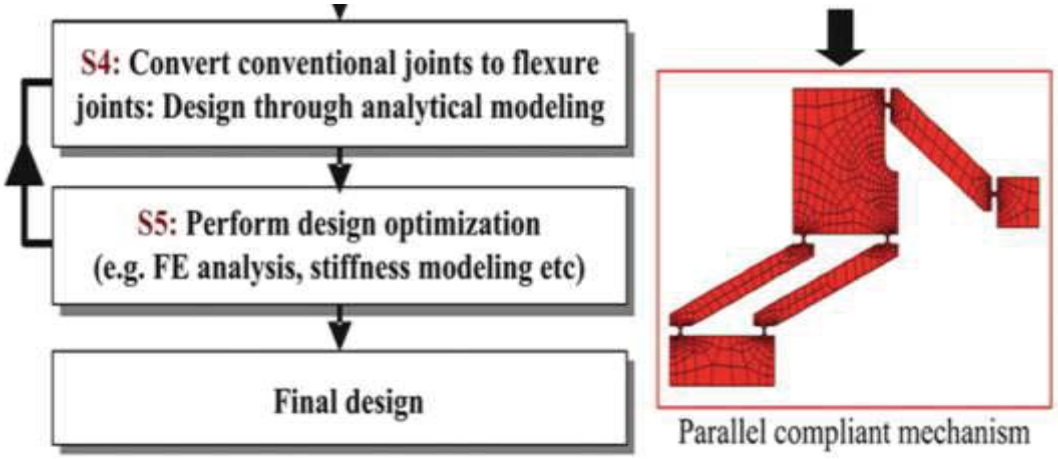

Fig. 5 Linkage-joint made up of parallel-kinematic architecture and parallel compliant mechanism [23]

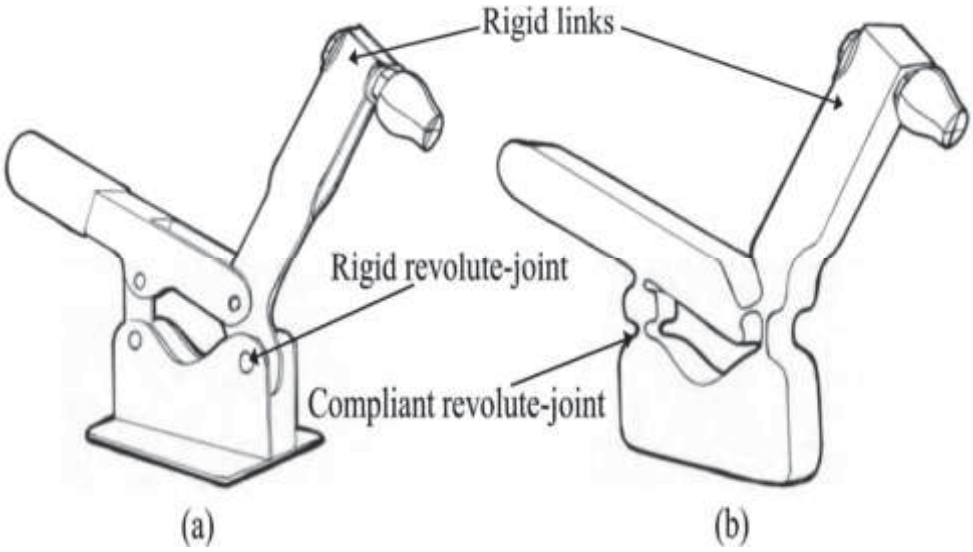

Fig. 6 Comparison between two joints made by different process [23]

From above figure (a) we can easily say that 2 joints which are made of conventional method of using bolts can easily convert in to figure (b) where it can be seen that two joints are made of monolithic connectors which has many advantages for instance, less material, easy design, and the main is reduction in cost [23].

4.3 There are several upsides of compliant mechanism which are mentioned as below:

1. The foremost advantage of compliant mechanism is there no need of assembly.so; the total structure is monolithic [16].
2. In this structure there is no need of lubrication so it reduces total cost of material [24].
3. Another most important factor is reduction in total number of parts results in less weight [24].
4. Designs are uncomplicated to unite with contemporary actuators [24].
5. Backlash can be eliminated, which is also great advantage [24].
6. Also, this non assembly structure has wide scope in medical industry in prosthetic body parts for instance, finger, hands, legs, bones replacement etc. [25].
7. Complex control system can be replaced by a compliant mechanism such as constant stiffness mechanism [26] and constant force mechanism [1].

4.4 There are also some demerits of monolithic mechanism which are given as below:

In this structure flexure pivot has restricted scope of motion because of configuration and stuff possessions [25]. Moreover, another significant problem is conventional flexure has bad structural effects exhibited when subjected to two or more axes freight [25].

- Due to presence of large deflections in compliant mechanism which ultimately cause increase in nonlinearities in both material behavior and geometry.[27]
- Also, in compliant mechanism direction of layer play a vital role to vary the stiffness by orders of magnitude.[27]
- High stress concentration must be kept away in order to reduce the risk of failure and material fatigue due to faulty design.[27]

It is concluded that there is difficulty in analyzing and designing complaint mechanisms [10].

5. Comparison of 3D printing with conventional methods for manufacturing compliant mechanisms

For compliant mechanism processes are selected on the basis of their characteristics. Here three processes are mentioned and selections of them in different applications are divided into mainly three criteria. First of all, large size mechanism in which moulding method is more advisable. Secondly, complex size and millimetre size mechanism in which 3D printing is more preferable. Lastly, in the mechanism which possesses high strength then in that case milling method is more advisable [28].

5.1 Materials and their applications in compliant mechanism

- The most common materials which are used in elements of compliant mechanism are mainly gold, epoxy resins, silicon and acrylic, polymethyl methacrylate. Moreover, widely used materials for micro compliant mechanism are mono and polycrystalline silicon, silicon nitride, nickel and copper [28].
- Another commonly used material is thermoplastic elastomer (fila flex) which is applicable in soft robotic finger [29].
- Combination of two or more material can be used as demonstrated by John A. Mirth where they used PLA and ABS using Fused Filament Fabrication method [30]
- PA2200 based on polyamide 12 is also convenient because of its biocompatible characteristics and used in 3D printed robot which is used in ENT surgery [19]. Further, high strength nylon plays an important role in compliant mechanism of three phalanax under actuated prosthetic finger [21]. Polyurethane is also an important material which has multiple usages namely interlocking joints for locking 3D printed components simultaneously, joining panels in automobile and construction factories [22].

6. Conclusion

- Compliant mechanism is used in many special applications and 3D printing is turning out be go to method of manufacturing this component.
- Some applications of compliant mechanism require a custom design such as in the case of prosthetics.
- 3D printing is a viable option to manufacture this kind of custom part where conventional methods are more suitable for mass production.
- There are relatively a smaller number of materials available to manufacture this component which limits their use and capabilities.
- Also Design of compliant mechanism is a complex and difficult task.
- With the growing use of compliant mechanism and development in 3D printing technology one can conclude that 3D printed compliant mechanism has great potential for special applications.

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