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DIRECT MANUFACTURE OF NON-ASSEMBLY MECHANISM BY SELECTIVE LASER MELTING

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ABSTRACT: Mechanism that is designed and assembled digitally and lately manufactured directly without post-assembly is called non-assembly mechanism. Selective Laser Melting(SLM) is a desirable technology for manufacturing non-assembly mechanisms directly as it can make complex functional parts directly. The critical factors of manufacturing non-assembly mechanisms by SLM such as display strategy and dimensional accuracy of clearance character are investigated in this paper. Non-assembly mechanisms such as Copper Cash Abacus and Collapsible Abacus, planar linkages (slider-crank, crank-rocker, rocker-slider) and universal joint, etc are freely designed and are manufactured by DiMetal-100 series SLM equipment. It is shown that SLM can not only manufacture parts with complex structures successfully, but also can manufacture non-assembly mechanisms with motion performance directly. It provides a feasible method for the digital design and integrated fabrication of mechanical and electronic products.

KEY WORDS: Selective Laser Melting; freely design; non-assembly mechanism; clearance character; motion performance

INTRODUCTION

Modern machinery and equipment are the assemblies of multi-mechanisms. In conventional manufacturing process, it is general to manufacture all kinds of parts alone firstly. then assemble them into a whole mechanical equipment by rivet, pin, bolt, etc. These processes are not only tedious, but also need to consider assembly mode and connection methods. The mechanism that is prior assembled in computer and then is manufactured directly without post-assembly process is called non-assembly mechanism. Obviously, conventional machining such as milling, planing, grinding, etc are not able to manufacture non-assembly mechanisms, as non-assembly mechanism is put forward based on the rapid prototyping technology of discrete/accumulation principal.

So far, the direct manufacture of non-assembly mechanisms were seldom reported. Mavroidis et al. (2001) manufactured revolute joint, spherical joint and prismatic joint by SLA and SLS. DeLaurentis et al. (2004) manufactured multi-joint manipulator by SLA and studied on the clearance fabrication process in horizontal and vertical direction. In order to improve the processability of non-assembly joint, Cali et al. (2012) designed a new pattern revolute joint and spherical joint, and calibrated the joint motion and employed SLS to manufacture manipulator. Lioson et al. (2005)manufactured several historic mechanisms by 3D printing technique. Chen et al. (2011)designed a drum joint with minimum clearance of 0.1mm, whereas the minimum clearance of conventional joint can only achieves 0.15mm. All of the mechanisms manufactured by above are seldom applied to actual mechanism equipment. The main reasons are that the materials used by the techniques above are nonmetals, the dimensional accuracy, mechanical properties, etc can not meet the requirements of the mechanism equipment.

SLM is the research hotspots in current RP field as it can make complex functional parts directly. Su et al. (2013) conducted research on the digital design rules of fabricating non-assembly

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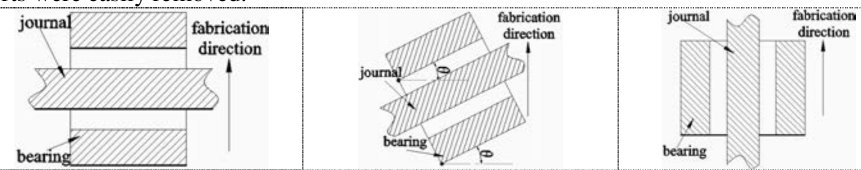
mechanism based on SLM and the early study on the influence of display strategy on clearance fabricating. However, the above research just focused on the feasibility of fabricating non-assembly mechanism by SLM without considering the critical issue: the direct fabrication of motion pair. The fabricating of non-assembly mechanism is a one-off process, but the parts with relative motion are jointed by motion pairs, the restricts of motion attributes still exist. So it needs to make sure that the manufactured motion pairs can meet the motion requirements of the mechanism. This paper investigates the key issues of fabricating non-assembly mechanism by using SLM, such as dimensional accuracy, clearance fabrication of non-assembly mechanism. At last, non-assembly abacuses and planar linkages, universal joint,etc are manufactured.

2 KEY ISSUES FOR FABRICATION OF NON-ASSEMBLY MECHANISMS BY SLM

2.1 Display strategy

Non-assembly mechanism consists of several parts, and reflects the connection relationship between two movable parts by clearance character. In fact, Non-assembly mechanism can be considered as one part with motion performance that consists of general structural characters and clearance characters. Therefore, the key issue of direct fabrication of non-assembly mechanism is fabricating the clearance characters. Due to effect of Laser Deep Penetration during the SLM, it must add supports to avoid arising of defect such as dross, deformation when the surface whose angle to the horizonal plane is smaller than the critical angle.

Clearance fit is employed between the journal and bearing which connect two movable parts. For a horizontal display, there are a lot of overhang structures within the clearance as the dark areas shown in fig. 1(a). The overhangs can be successfully manufactured by adding some supports, yet the supports cannot be removed if the clearances are too small. In contrast with the horizontal display, the clearance was tilting displayed at θ which is larger than the critical angle as shown in fig. 1(b). It can be seen that only a few supports were needed at the starting lines of the down-facing surfaces and supports were not needed within the clearance. At this configuration, the supports were easily removed.



(a) horizontal display | (b) tilted display | (c) vertical display

Fig. 1 Three types of display

2.2 Fabrication process of clearance character

To investigate the effect of thickness and energy input on the clearance character, clearance models with a series of tilt angle are manufactured. As shown in fig. 2. Tilt angle are $30°$, $35°$, $40°$, $45°$, $50°$. energy input could defined as P/v, to simplify the experiment design, the laser power is fixed as $150W$, and scan speed are $400mm/s$, $600mm/s$ and $800mm/s$, respectively.

Fig. 3(a) shows the clearance characters under the condition of $h = 25\mu m$, $v = 400mm/s$. It was found that the clearance character was warp seriously when $\theta = 30°$. It is indicated that in the case of a small tilt angle, the fabricating of clearance character is prone to failure due to large energy input. While θ is between $35°$ to $50°$, the clearance character is obvious. Fig. 3(b) shows the clearance characters under the condition of $h = 35\mu m$, $v = 400mm/s$. It is shown that there is much dross on the internal surface, especially when the tilt angle is small. the clearance is blurry even stuck, and the mobility of mechanism is reduced. Compared the result shown in fig. 3, it is indicated that clearance quality could be improved by reducing the layer thickness.

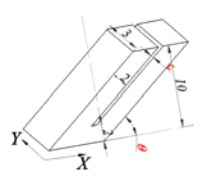
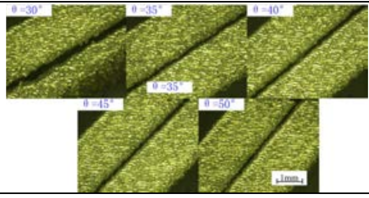
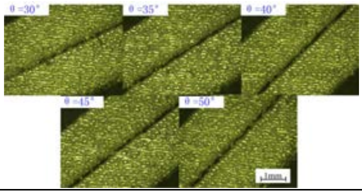


Fig. 2 Clearance character model



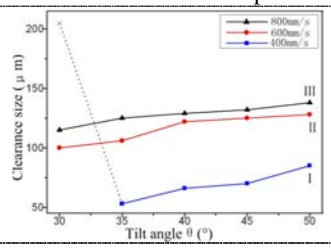
(a) h=25µm, v=400mm/s



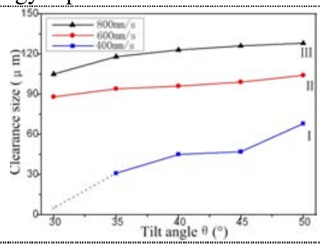
(b) h=35µm, v=400mm/s

Fig. 3 The manufactured clearance character with different tilt angles.

Fig. 4 shows the relationship between clearance size and thickness of when the scan speed varies from $400mm/s$ to $800mm/s$. It can be seen that as the tilt angle θ increases from $30°$ to $50°$, the clearance size also increases by about $30\mu m$. Compared curves of Ⅰ, Ⅱ and Ⅲ, it is found that in the case of certain tilt angle, the difference between curve Ⅰ and Ⅱ is $50 \sim 60\mu m$, while that of curve Ⅱ and Ⅲ is $20 \sim 30\mu m$. The reason can be drawn that the energy input corresponding to curve Ⅰ is 1.5 times and 2 times as much as that of curves Ⅱ and Ⅲ. Greater energy input, deeper the laser beam penetrates, and a portion of powder of the former layer is melt. The additional material adheres to the downward facing surface and becomes a part of the clearance. In order to reduce the impact of laser deep penetration effect on the fabrication of clearance character, it would be best to increase the scan speed to reduce energy input.



(a) h=25µm



(b) h =35µm

Fig. 4 The relationship between tilt angle and size of clearance character.

3 DESIGN AND DIRECT FABRICATION OF NON-ASSEMBLY MECHANISMS

The main steps of fabricating non-assembly mechanisms by SLM are as follows:

1) Establish the 3D model of each part of the mechanism and then conduct digital assembly to each part model in computer, thus the 3D model of the mechanism is got.

2) Conduct data processing to the 3D model of the whole mechanism taken as a part, such as format conversion, slicing, scanning path planning,etc.

3) Import the data into SLM fabrication equipment to directly manufacture the mechanism, thus, the real mechanism is obtained at last.

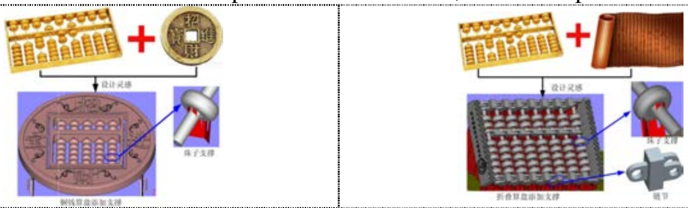
Compared with the conventional mechanism, the SLM non-assembly mechanism needs no subsequent assembly process, the assembly measure and space don't need to be taken into consideration in the design process, and the mechanism shape and structure can be designed more freely. In this paper, the processing parameters and scanning strategy are shown in table 1.

Table 1 Processing parameters and scanning strategy

Laser power (W)	Scan speed (mm/s)	Hatch space (mm)	Layer thickness (mm)	Scanning strategy
150	600	0.08	0.035	XY inter layer stagger

3.1 Direct fabrication of abacuses by SLM

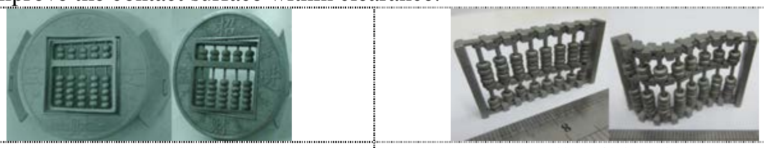
The progress of Additive Manufacturing provides a feasible method for direct fabrication of abacus. The design inspiration of the Copper Cash Abacus is shown in figure 5(a). It is the combination of ancient copper cash and abacus. It looks like a copper cash as a whole from the positive side with the abacus embedded into the central square hole which can rotate around the central axis. The design inspiration of the Collapsible Abacus is shown in figure 5(b) which combines the bamboo slip and the abacus together artfully. The Collapsible Abacus consists of frame, beam, rod and bead. The frame consists of chains that can rotate around each other. In order to make sure that the abacus move flexibly, clearances between the bead and the rod are set as 0.4mm, the other clearances are all set as 0.2mm. Patterns are added to the surface by means of directly manufacture metal relief from picture based on SLM, so as to improve the artistry.



(a) Copper Cash Abacus (b) Collapsible Abacus

Fig. 5 Design inspiration and CAD model of non-assembly abacuses

The abacuses were tilt displayed at 45° and manufactured. Fig. 6 shows the manufactured abacuses, sanding and sandblasting were used to improve the surface roughness, and repeated moving to improve the contact surface within clearance.



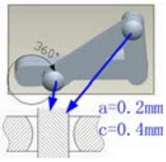
(a) Copper Cash Abacus (b) Collapsible Abacus

Fig. 6 Non-assembly abacuses directly manufactured by SLM

3.2 Planar Linkage Mechanism

3.2.1 Crank rocker mechanism

Crank rocker mechanism is the most typical and basic form of planar four-bar mechanism,which consists of crank, connecting rod, rocker and base as shown in fig. 7(a). The crank can rotate 360° and the rocker swing driven by connecting rod. The revolute joints were designed as drum shape to facilitate removal of powders within the clearances. The minimum clearance at the peak of drum was 0.2 mm. The mechanism was tilt displayed at 45° and manufactured. Fig.7(b) shows different positions of the manufactured mechanism. Angle between crank and base are 0°, 90°, 180°, 270°, respectively. The mechanism can achieve the designed performances well.



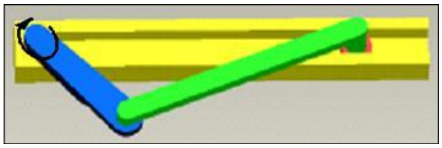
(a) Digital model

(b) Manufactured by SLM

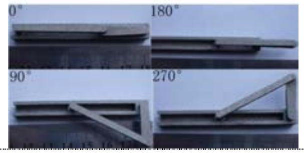
Fig. 7 Crank rocker mechanism

3.2.2 Slider crank mechanism

Slider crank mechanism is one of the most common planar linkage mechanisms. Fig. 8 (a) shows a slider-crank mechanism digital model, which consists of guide, crank, connecting rod, slider. The crank can rotates 360°, and the slider moves along the guide driven by the connecting rod. The revolute joints were designed as drum shape, and the minimum clearance at the peak of drum was 0.2 mm.The mechanism was tilt displayed at 45° and manufactured. and fig. 8 (b) shows different positions of the manufactured mechanism. Angle between crank and guide are 0°, 90°, 180°, 270°, respectively. The mechanism can achieve the designed performances well.



(a) Digital model

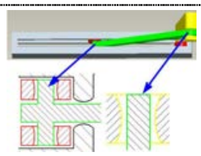


(b) Manufactured by SLM

Fig. 8 Slider crank mechanism

3.2.3 Rocker slider mechanism

Rocker slider mechanism is one of the common types of planar four-bar mechanism. Fig. 9 (a) shows a rocker slider mechanism digital model, which consists of rocker, connecting rod, slider and base. The revolute joints were designed as drum shape to facilitate removal of powders within the clearances, and the minimum clearance at the peak of drum was 0.2 mm. The mechanism was tilt displayed at 45° and manufactured as fig. 9 (b) shows. It shows different positions of the manufactured mechanism. The mechanism can achieve the designed performance.



(a) Digital model

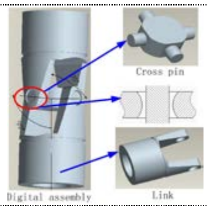
(b) Manufactured by SLM

Fig. 9 Rocker slider mechanism

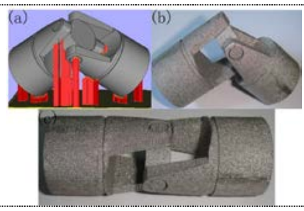
3.3universal joint

Universal joint is a common mechanism to transmit force. The conventional connecting cross pin was replaced with a simplified one to reduce the mechanism complexity as shown in fig. 10 (a), that conventional method can not assemble after fabrication. The joint was designed without requiring assembly. The minimum clearance was 0.2 mm.

Making the assembly angle between the two yokes at 90° and the clearance character was tilting displayed at 45°. It can be seen that only a few supports were needed at the starting lines of the down-facing surfaces and supports were not needed within the clearance characters. At this configuration, the supports were easily removed when the fabrication had finished. Fig. 10 (b) shows two angular positions of the manufactured joint, which verifies that the joint can rotate freely.



(a) Digital model



(b) Manufactured by SLM

Fig. 10 Universal joint

CONCLUSION

Non-assembly mechanism is based on the design theory of free structure which aims at realizing the function of mechanism, striving for the simplest shape and structure of parts. This idea releases the freedom of mechanism design tremendously, improves the innovative capacity of 3D mechanism models and can create new mechanisms with fine performances.

South China University of Technology has studied on the key issues of non-assembly mechanism manufactured by SLM, including display strategy, dimensional accuracy and surface roughness of clearance character, structural optimization. Non-assembly mechanisms such as abacuses, planar linkages(slider-crank, crank-rocker, rocker-slider), and universal joints, etc are freely designed and manufactured by DiMetal series SLM equipments.

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REFERENCES

Mavroidis C., DeLaurentis K. J. & Won J. (2001). Fabrication of non-assembly mechanisms and robotic systems using rapid prototyping[J]. J. Mech. Des., 123(4), 516-524.

DeLaurentis K. J. & Mavroidis C. (2004) Rapid fabrication of a non-assembly robotic hand with embedded components[J]. Assembly Automation, 24(4), 394-405.

Calì J., Calian D. A. & Amatiet C. (2012). 3D-Printing of Non-Assembly, Articulated Models[J]. ACM Transactions on Graphics, 31(6), 1-8.

Lipson H., Moon F.& Hai J. (2005). 3-D printing the history of mechanisms[J]. J. Mech. Des., 127(5), 1029-1033.

Chen Y.H.& Lu J. (2011). Minimise joint clearance in rapid fabrication of non-assembly mechanisms[J]. Int. J. Comput. Integ. M., 24(8), 726-734.

Su X., Yang Y. & Xiao D. (2013). Processability investigatation of non-assembly mechanisms for powder bed fusion process[J]. Int J Adv Manuf Technol., 64, 1193-1200.