Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 65 (2017) 1 – 6

www.elsevier.com/locate/procedia

3rd CIRP Conference on BioManufacturing

Suitability evaluation of various manufacturing technologies for the development of surgical snake-like manipulators from metals based on flexure hinges

Suat Coemert[a]*, Mattias F. Traeger[a], Eva C. Graf[a] and Tim C. Lueth[a]

[a]*Institute of Micro Technology and Medical Device Technology (MIMED), Technical University of Munich, Boltzmannstr. 15, Garching 85748, Germany*

* Corresponding author. Tel.: +49-89-289-15139; fax: +49-89-289-15192. *E-mail address:* suat.coemert@tum.de

Abstract

In our group, a snake-like surgical manipulator has been developed which was fabricated using selective laser sintering and a biocompatible polyamide. This paper describes a concept to substitute polyamide with biocompatible metals in order to miniaturize the available system. At this point, beside the design approach and the material selection, the preferred fabrication method plays a crucial role. Therefore various manufacturing technologies have been explored to investigate their suitability. These include prominent methods of additive manufacturing and machining technologies. In this paper, encountered advantages and disadvantages of each technique are listed and discussed to find the most suitable concept.

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on BioManufacturing 2017

Keywords: Snake-like manipulator; Minimally invasive surgery; Manufacturing methods; Flexure hinges; Biocompatible metals

1. Introduction

Minimally invasive surgery (MIS) is an intervention technique which uses natural orifices or small incisions to access the surgical sites. This allows patients to recover in a shorter period of time with less pain. As the surgeons usually do not have direct access to the surgical site as in open surgery, they have to rely on devices for control of the instruments and visualization of the operation site. At this point, robotic assisted surgery becomes an important tool to assist surgeons in general, urologic and gynecologic surgery [1]. However the existing robotic technology is challenged by many surgical applications (e.g., skull base surgery) that constitute various anatomic constraints. As a result, the prospective surgical robots/manipulators intended for such applications should possess some key features such as being small in size, flexible, steerable and robust.

At the Institute of Micro Technology and Medical Device Technology at the Technical University of Munich, Krieger et al. have developed a multi arm surgical snake-like manipulator which was manufactured by Selective Laser Sintering (SLS) using a biocompatible polyamide [2]. The prototype of the developed system is shown in Fig. 1. This system consists of a flexible overtube structure which is guided by the steerable tip of an endoscope inserted into its endoscope channel and two additional arms attached to the tip of the overtube. The two manipulator arms on the tip allow the independent steering of the flexible endoscopic instruments. The manipulator arms are actuated by Bowden cables and each arm has three rotational degrees of freedom. The kinematics of the system is realized by flexure hinges. This manipulator is 22 mm in diameter and was developed for endoscopic submucosal dissection (ESD) in the gastrointestinal

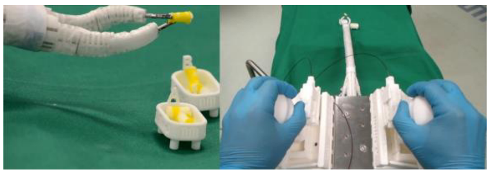

Fig. 1. Prototype of the multi-arm snake-like manipulator, fabricated by selective laser sintering of a biocompatible polyamide

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on BioManufacturing 2017
doi:10.1016/j.procir.2017.03.108

tract with the esophagus used as the access route. This system has proven itself to be a good concept for developing a surgical manipulator and it is designed as a disposable device, since laser-sintered polyamide is subject to blood contamination and cannot be sterilized for a second use.

The ultimate objective of this work is to develop a snake-like manipulator for minimally invasive surgery based on flexure hinges using biocompatible metals. If we consider aforementioned requirements of MIS and the blood contamination problem of the polyamide, the reason for choosing metals can be based on two facts: First of all, metals are less prone to blood contamination so they can be sterilized and reused whereas polyamide surgical products are only suitable for single use. Secondly, size reduction is possible thanks to the stiffer nature of metals. However, some requirements should be met in order to come up with a proper concept. These are explained as follows:

1.1. Technical safety

Since the system is intended to be used inside the human body, it has to meet the safety requirements of the medical devices law. Therefore, it must be proved by tests according to the international standards that the used materials and the production processes will not lead to any biological and mechanical danger during the clinical use.

1.2. Flexibility

Flexibility of the manipulator structure is provided by flexure hinges. The geometry of a single flexure hinge is similar to a cantilever beam with rectangular cross section and the bending of a single flexure hinge under the exposure of moment end load can be depicted with Fig. 2. Since flexure hinges undergo large deflections, analyzing their deflections with classical Bernoulli-Euler beam theory equations would be misleading to estimate the exact deflection amount [3]. Nevertheless, it is evident that the deflection amount is proportional to the beam length *l* and inversely proportional to the flexural rigidity *EI*, where *E* is the elasticity modulus of the corresponding material and *I* is the areal moment of inertia of the rectangular cross section. For the bending case represented in Fig. 2, *I* is dependent on the parameters beam thickness *h* and the beam width *b*:

$$I = \frac{b\,h^3}{12} \tag{1}$$

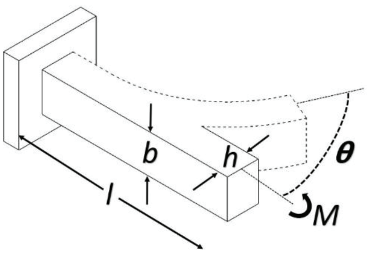

Fig. 2. Large deflection of a cantilever beam under exposure of moment

Based on these facts, we can state that modifying the beam dimensions and choosing a metal with low elastic module would be an effective way to increase flexibility. Since *E* is much lower for polyamide than for metals, the beam thickness *h* and the beam width *b* could be decreased whereas *l* could be increased to obtain similar flexibility for the continuum structures manufactured from metals compared to those made of polyamide.

1.3. Strength

While modifying beam dimensions to increase the flexibility, it must be considered that this action leads to a decrease in the strength of the flexure hinge [3]. If a cantilever beam is exposed to a larger deflection than its yield strength allows, then yielding occurs and the beam fails. The maximum allowable deflection δ_{max} for a rectangular cross section cantilever beam can be expressed with eq. (2). Based on these considerations, the flexure hinge must be designed in a way that the maximum deflection amount is constrained to a level where the maximum stress at the fixed end equals to the yield strength of the corresponding material σ_{yield}. This restriction can be provided by adjusting the gap width at the sides of the flexure hinge (Fig. 3).

$$\delta_{max} = \frac{2\,l^2 \sigma_{yield}}{3\,E\,h} \tag{2}$$

Another strategy to achieve a good trade-off between the flexibility and the strength is to select a material which has a high σ_{yield}/E ratio [3]. For instance the flexure hinges made of such materials with the same geometry and the same loading conditions will provide larger deflections compared to the others. Among the metals, Ti6Al4V ELI and nitinol become prominent with their high yield strength to elastic module ratio and biocompatibility.

1.4. Geometry

Depending on the medical application the outer diameter (OD) of the manipulator will be limited to 5 mm for one-instrument-manipulation and to 10 mm for double-instrument-manipulation (Fig. 4). The visualization will be provided by an endoscope and the manipulator will function as a guiding frame for the endoscope and surgical instruments. Additionally, the surgeon will be able to manipulate the surgical tools by a joystick-like user interface in multiple deg-

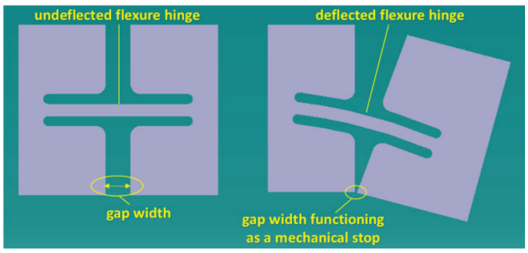

Fig. 3. Constraining the deflection amount of a flexure hinge by using the gap width as a mechanical stop